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AIR POLLUTION/LAND USE PLANNING PROJECT VOLUME III. AN ECONOMIC COMPARISON OF POINT-SOURCE CONTROLS AND EMISSION DENSITY ZONING FOR AIR QUALITY MANAGEMENT

A. S. Kennedy, et al

Argonne National Laboratory

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by

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ABSTRACT

The purpose of this study is to assess the value of land use zoning policies in achieving and maintaining air quality standards in existing large urban areas, or in smaller but rapidly developing areas. The traditional permitted-use zoning policies, as well as the more recent emission-density-limited zoning concept, are evaluated and compared with current source control regulations being adopted in most state implementation plans. A systematic air pollution control policy evaluation methodology has been developed to carry out the evaluations. The results of a applying this methodology to a three-county area in the Chicago Metropolitan Control Region are presented in this report.

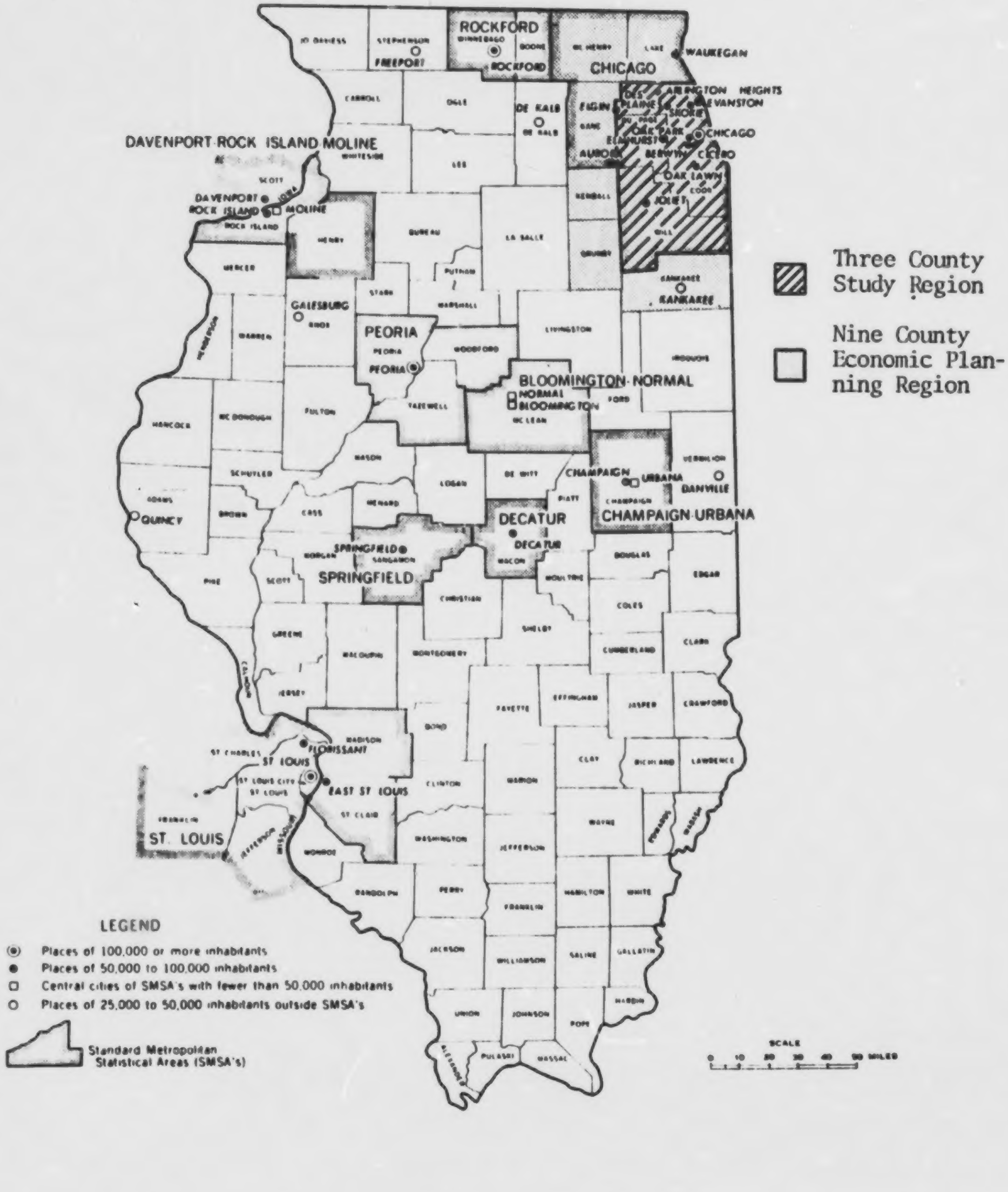
1.0 INTRODUCTION

The purpose of this study is to assess the value of zoning policies in achieving and maintaining air quality standards in existing large urban areas, or in smaller but rapidly developing areas. A review of the literature in regional air pollution control policy (Appendix A) has indicated that typical point-source control regulations have not been routinely subjected to systematic evaluation or compared against other forms of regional control. This situation is particularly acute when questions of urban development, air quality degradation, and maintenance of ambient air quality standards are raised.

This study suggests some answers to the following questions:

1) How can regional air quality be maintained as regional land use patterns change?
2) Are land use guidance and zoning policies useful in maintaining air quality? How do they compare to point-source controls when evaluated using economic criteria such as cost, resource utilization, effectiveness, and equity?
3) Can point-source controls and zoning policies be combined to achieve a more effective air pollution control program?
4) How sensitive are the costs and effectiveness of alternative control policies to adjustments in policy parameters?

To answer these questions, this study has developed a systematic air pollution control policy evaluation methodology and applied it to three county areas in the greater Chicago metropolitan region. The study subregion consists of Cook, Will, and Dupage counties, as shown in Figure 1.1. This area accounts for a major portion of industrial activity in the region. The study methodology is described in Section 2 of the report, and the results of the application are presented in Section 3. A brief summary of conclusions drawn from the results is presented in Section 4. Appendices A and B contain details of literature review and a description of a point-source, cost-effectiveness model developed to carry out the evaluations.


ROCKFORD
CHICAGO
WAUKEGAN
ARLINGTON HEIGHTS
EVANSTON
CHICAGO
ELGIN
AURORA
JOLIET
KANKAKEE
DAVENPORT-ROCK ISLAND-MOLINE
DAVENPORT
ROCK ISLAND
MOLINE
FREEPORT
DE KALB
GALESBURG
PEORIA
BLOOMINGTON-NORMAL
NORMAL
BLOOMINGTON
CHAMPAIGN
URBANA
DANVILLE
CHAMPAIGN-URBANA
DECATUR
QUINCY
SPRINGFIELD
FLORISSANT
ST LOUIS
EAST ST LOUIS
ST. LOUIS
Three County Study Region
Nine County Economic Planning Region
LEGEND
Places of 100,000 or more inhabitants
Places of 50,000 to 100,000 inhabitants
Central cities of SMSA's with fewer than 50,000 inhabitants
Places of 25,000 to 50,000 inhabitants outside SMSA's
Standard Metropolitan Statistical Areas (SMSA's)
SCALE
0 10 20 30 40 50 MILES

U.S. DEPARTMENT OF COMMERCE Social and Economic Statistics Administration BUREAU OF THE CENSUS

Figure 1.1. State of Illinois, Chicago economic planning and statistical reporting region.

2.0 STUDY METHODOLOGY

Most air pollution control problems can be solved in several ways. In order to select the preferred method of regulating pollutant emissions from manufacturing processes, each solution should be thoroughly evaluated prior to implementation. In this study, two approaches to regional air pollution control regulations, point-source controls (PSC) and emission-density-limited zoning (EDLZ), are quantitatively evaluated and compared. A systems model was constructed to carry out these evaluations. By using this model, a regulatory system can be selected that meets the design requirements of each manufacturing process, achieves the necessary reduction of pollutants required to satisfy air quality standards, and attains these goals at lowest overall cost.

This section describes briefly the methods used in constructing the model and applying it to the Chicago region.

2.1 SYSTEM MODEL DESCRIPTION

The system model developed for the evaluation and comparison of the two regulatory methods is diagrammed in Figure 2.1. The entire model is actually a linking of three submodels:

1) A control regulation model
2) A cost model
3) An atmospheric dispersion model.

The control regulation model accepts as input either a point-source or a land use regulation and applies it to each point source on the regional emission inventory to compute the reductions required by the regulation.

The cost model selects the device that meets the technical requirements of each individual plant and achieves the required reductions. If

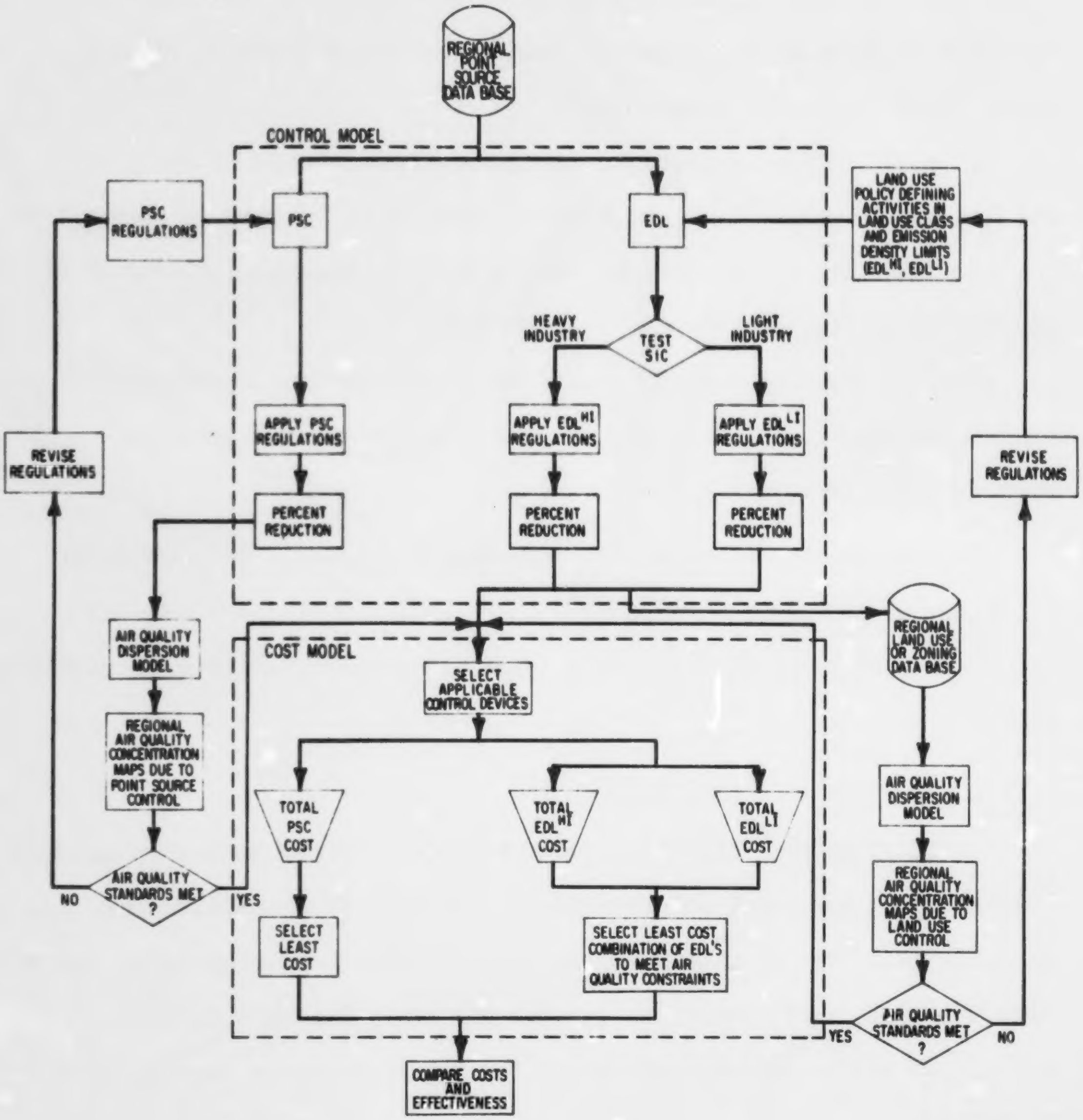

REGIONAL POINT SOURCE DATA BASE
CONTROL MODEL
PSC REGULATIONS
PSC
EDL
LAND USE POLICY DEFINING ACTIVITIES IN LAND USE CLASS AND EMISSION DENSITY LIMITS (EDL^HI, EDL^LI)
HEAVY INDUSTRY
TEST SIC
LIGHT INDUSTRY
APPLY PSC REGULATIONS
APPLY EDL^HI REGULATIONS
APPLY EDL^LI REGULATIONS
REVISE REGULATIONS
REVISE REGULATIONS
PERCENT REDUCTION
PERCENT REDUCTION
PERCENT REDUCTION
AIR QUALITY DISPERSION MODEL
REGIONAL LAND USE OR ZONING DATA BASE
COST MODEL
SELECT APPLICABLE CONTROL DEVICES
REGIONAL AIR QUALITY CONCENTRATION MAPS DUE TO POINT SOURCE CONTROL
TOTAL PSC COST
TOTAL EDL^HI COST
TOTAL EDL^LI COST
AIR QUALITY DISPERSION MODEL
REGIONAL AIR QUALITY CONCENTRATION MAPS DUE TO LAND USE CONTROL
NO
AIR QUALITY STANDARDS MET ?
YES
SELECT LEAST COST
SELECT LEAST COST COMBINATION OF EDL'S TO MEET AIR QUALITY CONSTRAINTS
YES
AIR QUALITY STANDARDS MET ?
NO
COMPARE COSTS AND EFFECTIVENESS

Figure 2.1. Model for comparison and evaluation of emission control approaches

more than one device is applicable, the least costly device is chosen. The ammortized cost of control is calculated as the sum of capital, depreciation, operating, and maintenance charges. Details of the cost model are relegated to Appendix B. Costs are accumulated in the model by SIC code, zoning class, and total manufacturing.

In operating the various equipment, the commodities of water, power and fuel may be used. The quantities used and costs incurred by these items are calculated and accumulated for the purposes of measuring the impact of control regulations on resource utilization.

Both the strategy and cost models are constructed in a general fashion, so that they are readily adapted to purposes other than the specific tasks performed in the study.

The atmospheric dispersion model is used to calculate and to display the impact of each type of regulation on regional air quality. The Air Quality Display Model (AQDM)[1,2] calibrated to the Chicago region was used for this purpose.

2.2 SYSTEM MODEL DATA REQUIREMENTS

In applying the system model to compare and evaluate emission-density-limited zoning and point-source controls, the Chicago metropolitan regional emission inventory was utilized. The regional data file consists of source identification, fuel combustion, process emission, and stack data. A description of the data as recorded in the inventory can be seen in Table 2.1.

The data for 475 sources in the Chicago study region, which consisted of the city itself and the three surrounding counties of Cook, Will, and DuPage, were available from the Illinois State Implementation Planning Program. The data were collected during the summer of 1971 by a team

Table 2.1. STATE OF ILLINOIS EMISSION INVENTORY FILE PARAMETERS

Source Identification	Fuel Combustion	Process Emission Source	Stack Data
Source identification number	Boiler capacity (10^6 BTU/hr)	Emission factor table code	Height (ft)
Source name	Coal (tons/year)		Inside diameter (ft)
		Process quantity	
Source street address	Oil (10^3 gal/year)		Temperature (°F)
		Process weight rate (lb/hr)	
City	Oil grade		Velocity (ft/sec)
Zip code	Gas (10^6 ft^3/year)	Process name	Gas volume (acf/sec)
Geocode	Heat content:	Emission factor	Number of units
X-Coordinate (Km)	Coal (10^3 BTU/lb) Oil (10^3 BTU/gal)	Emissions (lb/hr)	
Y-Coordinate (Km)	Gas (BTU/ft^3)		
Standard land use classification number	Percent ash coal		
	Particulate emission factor		
Lot size (acres)			
Employees	Emissions (lb/hr)		
Zoning			

of students, who, under the supervision of the Argonne Center for Environmental Studies, surveyed the entire state for manufacturing source information. The Census Bureau publications, "County Business Patterns in Illinois" and the "Directory of Manufacturers," were used to guide the information collection operations. The Illinois State emission inventory contains planning and economic parameters such as land use, employment, energy consumption by type of fuel, and process output data, in addition to emission information.

Emission factor information was used to derive total emissions from data surveyed. No direct emission testing was performed in collecting these data. Information was obtained by secondary source review, telephone contact, or site visit. It should be noted that the City of Chicago supplied combustion information to the State directly in their own format. Therefore, fuel combustion from manufacturing sources within the city proper was not collected in the survey. The emission factors utilized in the conversion equations were obtained from the U.S. Environmental Protection Agency.[3]

In addition to point-source information, the model requires land use information to carry out the evaluations. For purposes of this study, manufacturing land use was divided into two categories—heavy industrial (HI) and light industrial (LI). Current land use information for the Chicago region was obtained from the regional planning body, the Northeastern Illinois Planning Commission (NIPC). Zoning information was obtained directly from the counties in the region. The land use and zoning inventories were collected on a square-mile basis for the Chicago region, and computerized as fractions of land area zoned for each land use class.

Finally, the model requires that a permitted-use zoning policy be established. This was accomplished by a survey of county zoning administrators.* The results indicate that heavy and light industrial activities are most commonly defined as shown in Table 2.2.

2.3 POINT-SOURCE CONTROL REGULATIONS

Point-source control regulations are usually defined as a function of plant size or for particulate process control. The most common parameter for this purpose is process weight rate, or the sum of all primary materials processed through the plant. The State of Illinois has adopted a version of a regulation commonly referred to as the "Bay Area Curve" for process particulate pollutant control. This regulation and its rationale are reviewed further in Appendix A. Fuel combustion particulate emissions are regulated in relation to the total Btu input to the plant.

Given the parameters of the regulation, the process of evaluation in the system model is fairly straightforward. The control model is executed to determine required reductions for each plant in the file. These reductions are then fed directly into the air quality dispersion model and the cost model.

2.4 PERMITTED-USE ZONING AND EMISSION-DENSITY ZONING REGULATIONS

Permitted-use zoning of manufacturing land is one of the earliest forms of nuisance control. Typically, zoning classes are defined and land use maps are prepared; these regulate the type and location of specified activities. Since air quality concentrations are partially determined by the spatial distribution and intensity of sources, it is reasonable to ask if point-source control regulations, combined with permitted-use zoning, is sufficient to ensure air quality maintenance.

To test this assumption, it is necessary to look at the distribution of emission densities within each land use or zoning class. This has been

---

*Source: Cohen, A.S., Norco, J.E., et al. Evaluation of Emission Control Strategies with Emphasis on Residential/Commercial Space Heating for SO_2 and Particulates in the Chicago Metropolitan Air Quality Control Region. March 1971.

Table 2.2. ACTIVITIES BY ZONING CLASS

Heavy Industry		Light Industry	
SIC	Description	SIC	Description
26	Paper and Allied Products	20	Food and Kindred Products
27	Printing, Publishing, and Allied Industries	21	Tobacco Manufactures
28	Chemicals and Allied Products	22	Textile Mill Products
29	Petroleum Refining and Related Industries	23	Apparel & Other Finished Products Made from Fabrics & Similar Materials
30	Rubber and Miscellaneous Plastic Products	24	Lumber & Wood Products, Except Furniture
31	Leather and Leather Products	25	Furniture and Fixtures
32	Stone, Clay & Glass Products	34	Fabricated Metal Products, Except Ordnance, Machinery, & Transportation Equipment
33	Primary Metal Industries	35	Machinery, Except Electrical
		36	Electrical Machinery, Equipment, and Supplies
		37	Transportation Equipment
		38	Professional, Scientific, and Controlling Instruments; Photographic and Optical Goods; Watches and Clocks
		39	Miscellaneous Manufacturing Industries

done for the Chicago region using the activity assignment by 2-digit SIC defined in Section 2.2 for heavy and light industry and assuming the Illinois point-source regulations are in effect.

Figure 2.2 shows the emission-density distribution of industrial class sources within the Chicago area. Not only is the standard deviation of this distribution quite high in relationship to its average, but the skewness of the distribution causes significant estimation problems if a figure of 1.17 lbs/hr/acre is used as an emission-density factor in projecting future air quality. The use of mean emission-density estimates for projecting air quality from land use was tested by using the AQDM atmospheric dispersion model. Figure 2.3 shows the calculated air quality for suspended particulates as derived by applying a 1.17 lb/hr/acre emission-density factor to the present industrial land use pattern in the City of Chicago. Figure 2.4 shows the suspended particulate air quality estimates based directly upon the application of standard emission factors to the Chicago Emission Inventory with Illinois source control regulations applied. The use of the average emission density factor for industrial lands did produce average air quality estimates that approximated the average air quality over the entire region. However, due to the bias in the estimation of the average emission-density factor and within clusters of manufacturing land use in the area, pockets of very high concentrations appear in the air quality estimates based upon these factors, as opposed to those based upon the standard emission factors. Thus, if these estimates are used in trying to identify future potential source clusters in the Chicago area, the use of an average emission density to generate air quality estimates would lead to the belief that air quality standards would not be met under the present conditions of Chicago land use patterns and air quality regulations.

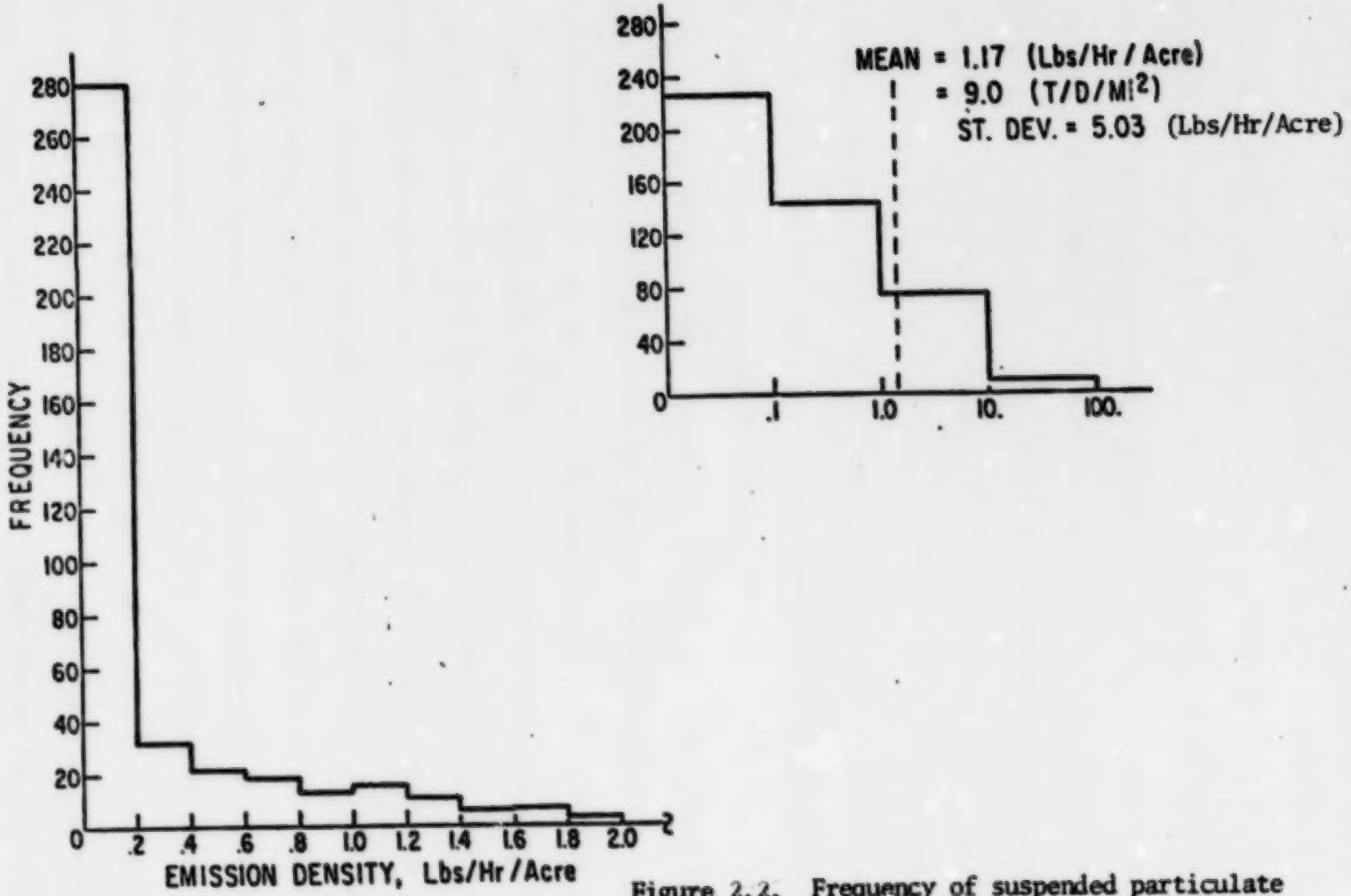


Figure 2.2. Frequency of suspended particulate emission-density with Illinois point-source regulations applied

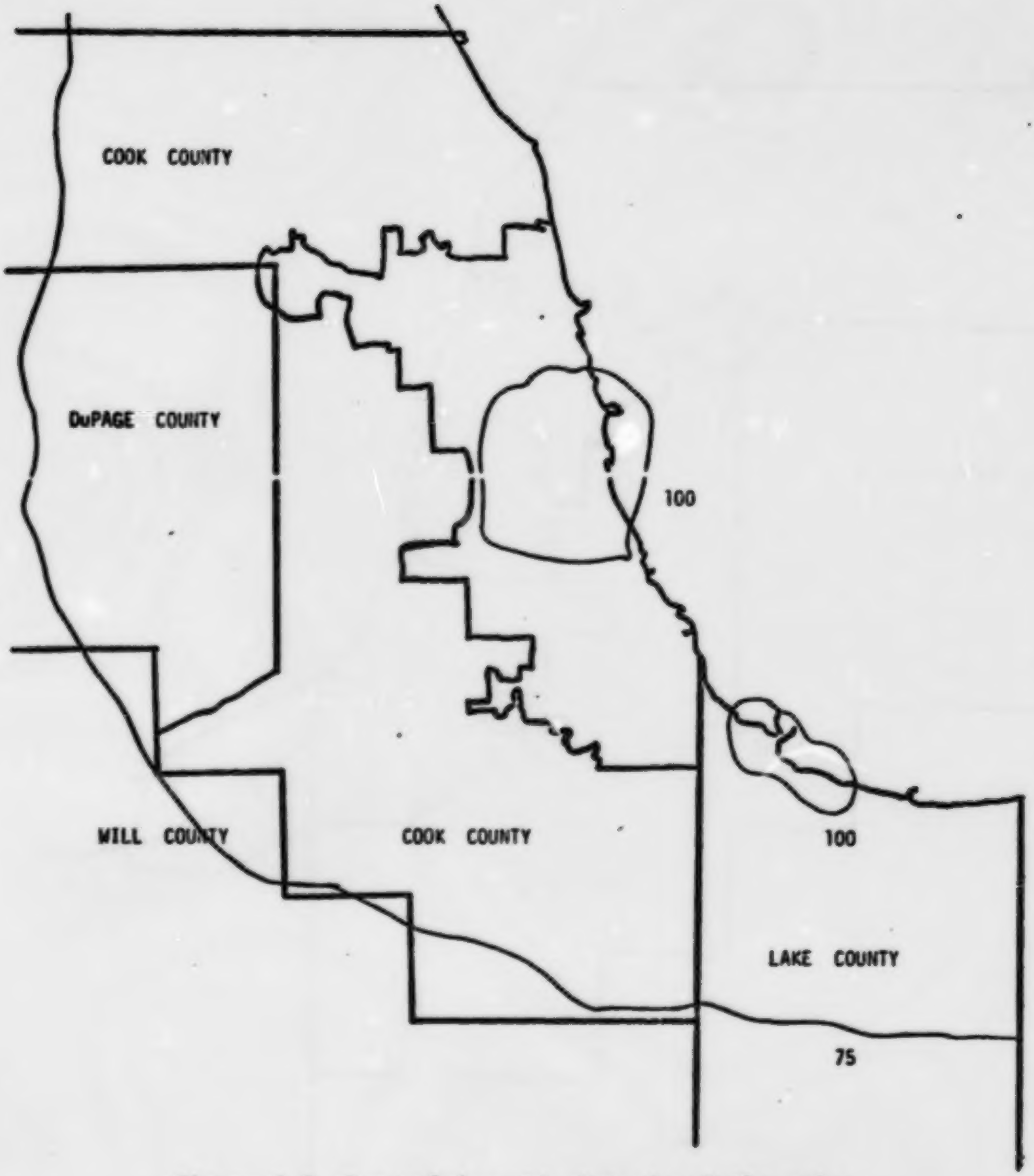


Figure 2.3. Suspended particulate isopleths using mean emission-density estimates for manufacturing land (mean = 1.17 lb/hr/ac = 9.0 t/d/mi^2) (μg/m^3, annual geometric mean)

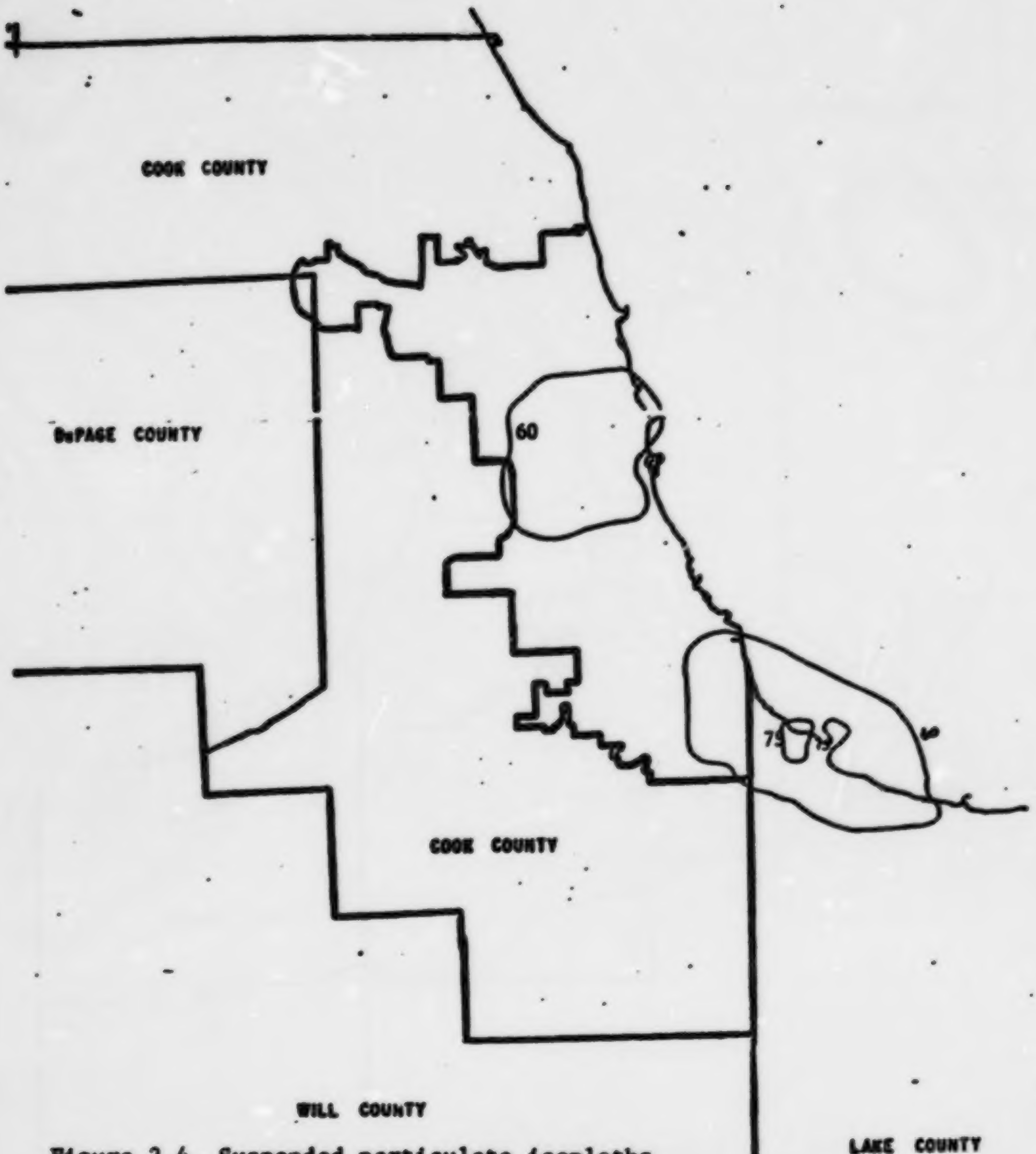


Figure 2.4. Suspended particulate isopleths with Illinois source regulations applied
($\mu g/m^3$, annual geometric mean)

The use of mean density estimates by manufacturing zoning class to estimate air pollution concentrations was also tested using the AQDM model. Parameters describing the emission density distributions for heavy and light industry are shown in Table 2.3. Again, the highly skewed distributions can be noted. When the mean estimates are applied to light and heavy manufacturing land use in the Chicago area, a slightly better air quality representation is obtained, as shown in Figure 2.5. The peak areas are represented more accurately than before, but the magnitude of the peaks remains much too high. It can be inferred from this result that, because of the extreme variance in manufacturing emission densities by zoning class, permitted-use zoning on a heavy and light industry taxonomy is not discriminatory enough to serve as an effective device for ensuring the maintenance of air quality standards even when coupled with point-source controls. The limited success of further explaining the above-noted variance has been discussed in Volume II of this report. Therefore, some means of limiting the extent of source clustering, and hence, emission densities, is required to avoid the possibility of future degradation. Two additional methods are available: (1) limiting the location of significant sources via an environmental impact statement process or permit-to-locate system; or (2) a comprehensive emission-density zoning process. The remainder of this volume focuses on the latter alternative.

2.5 EMISSION-DENSITY-LIMITED ZONING

Emission-density-limited zoning regulations are restrictions on the amount of emissions per unit of land area by zoning. They take the form of emission-density constraints; for example, a regulation forbidding emission of more than 200 pounds of particulates per day per acre of land could be enacted. Such a regulation would require that a large emitter either reduce the number of tons per day emitted or have sufficient non-polluting property to reduce the emissions per acre to acceptable levels.

Table 2.3. SUSPENDED PARTICULATE EMISSION-DENSITY (Lbs/Hr/Acre)

G_A^1 {26-33} G_A^2 {20-25, 24-39}	Unregulated Source Inventory				Regulated Source Inventory			
	Mean	Median	Std. Dev.	Skewness	Mean	Median	Std. Dev.	Skewness
G_A^1 (255)	47.60	.717	472.65	15.48	1.67	.21	6.29	7.63
G_A^2 (203)	27.24	1.04	164.76	9.63	.54	.04	2.62	8.35
TOTAL	38.57	.92	369.14	18.476	1.17	.104	5.03	9.01
ANOV					F= 5.65	1 DF=454		S(.05)

*F - F ratio

DF - Degrees of freedom (DFB - Between / DFW - Within)

S - Significance level

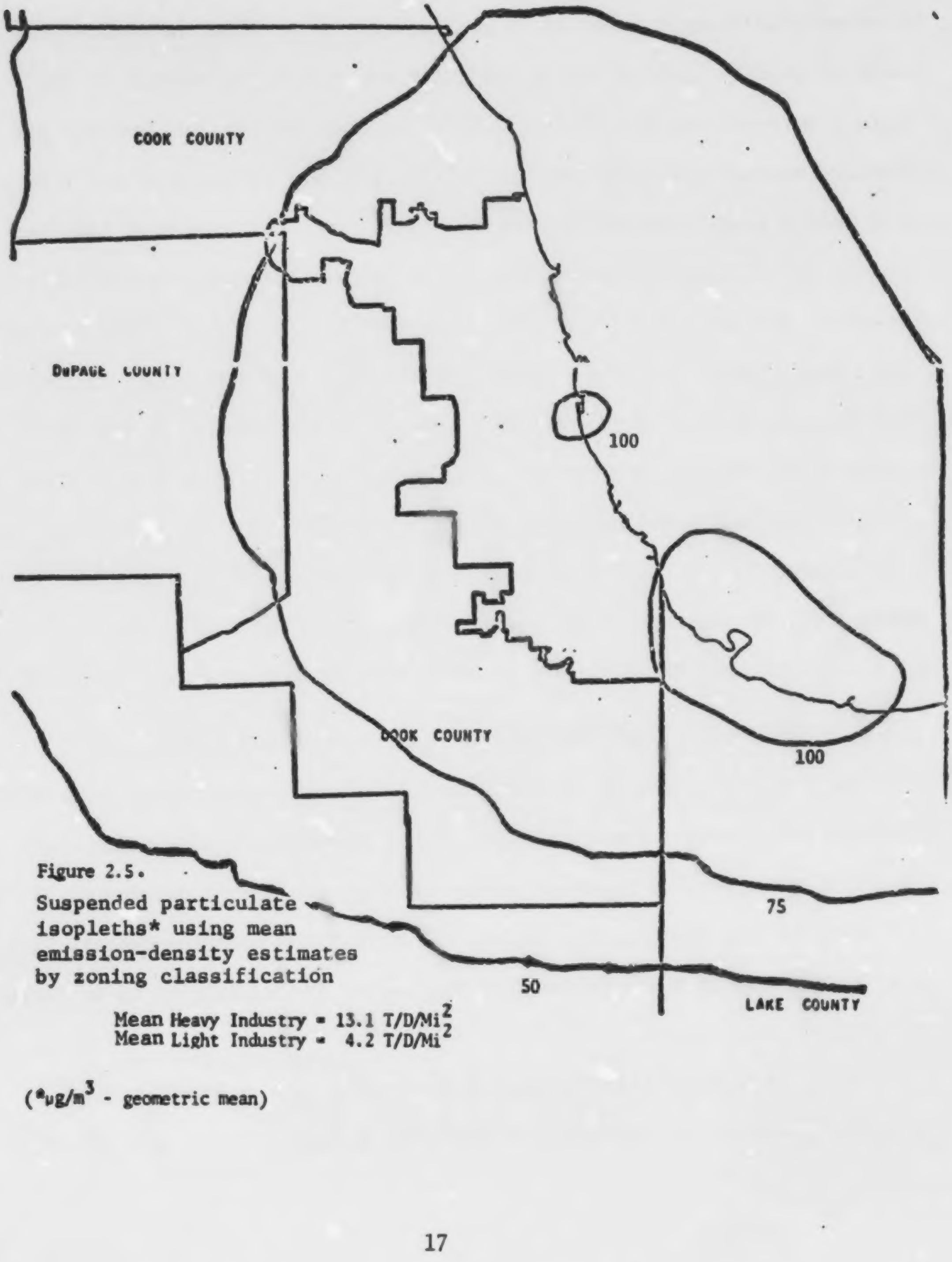


Figure 2.5.
Suspended particulate isopleths* using mean emission-density estimates by zoning classification

Mean Heavy Industry = 13.1 T/D/Mi^2
Mean Light Industry = 4.2 T/D/Mi^2

(*$\mu g/m^3$ - geometric mean)

Cook County, Illinois, one of the counties in the study region, is one of the few areas in the country to have passed an emission-density-limited zoning ordinance. The allowable emission-density limits (EDL's) for each of three manufacturing classes are shown in Table 2.4. When the Cook County Emission Density Limited Zoning Ordinance was applied to sources in the Chicago Metropolitan Air Quality Control Region, the national ambient air standard was not met. The standard of 75 $\mu g/m^3$ was violated in the region with both present land use and current zoned land. With present land use and the Cook County Ordinance, the entire Chicago Metropolitan Air Quality Control Region is above the standard, as seen in Figure 2.6. With current zoned land, Figure 2.7, the standard is also exceeded throughout the region with clusters formed in the downtown Loop area, the steel-mill area in northwestern Indiana, and the industrial area surrounding Joliet, Illinois. In order to compare and evaluate the two alternative control approaches under investigation, an effective emission-density-limited zoning ordinance that meets the national ambient air standards must be formulated. Thus, the question is raised as to how the emission-density limits should be specified.

2.6 SPECIFICATION OF EMISSION-DENSITY LIMITS BY ZONING CLASS

In the formulation of an effective EDLZ policy, air quality must be achieved throughout the entire region. For purposes of calculation with the AQDM atmospheric dispersion model, the air quality is determined at 237 receptor locations in the region. Thus, maximum emission-density limits are constrained to those values that will allow air quality to be achieved at each of these points.

If it is assumed that the region is divided into geographic grid squares indexed by ℓ, that k is an index of receptor points, and that m is

Table 2.4. COOK COUNTY EMISSION-DENSITY LIMITS (EDL) BY MANUFACTURING ZONE

ZONE 1

In unincorporated areas includes all residential and business districts and the M1 manufacturing district, as established and defined in the Cook County Zoning Ordinance. In incorporated areas includes residential, business, and restricted manufacturing districts, or the most restrictive manufacturing district as defined in the applicable local zoning ordinance.

Particulate Matter The rate of emission of particulate matter from sources within the boundaries of any lot shall not exceed a net figure of 1 lb/acre of lot area during any one hour, after deducting from the gross hourly emission per acre the correction factor set forth in the following table:

Allowance for Height of Emission[a]

Height of Emission Above Grade (ft)	Correction (lbs/hr/acre)
50	0.01
100	0.06
150	0.10
200	0.16
300	0.30
400	0.50

[a] Interpolate for intermediate values not shown.

Table 2.4. (Contd.)

ZONE 2	
In unincorporated areas includes the M2 and M4 manufacturing districts, as established and defined in the Cook County Zoning Ordinance. In incorporated areas include any general manufacturing district other than the most restrictive and most intensive manufacturing district as defined in the applicable local zoning ordinance.	
Particulate Matter	The rate of emission of particulate matter from sources within the boundaries of any lot shall not exceed a net figure of 3 lb/acre of lot area during any one hour, after deducting from the gross hourly emission per acre the correction factor set forth in the following table:

Allowance for Height of Emission[a]

Height of Emission Above Grade (ft)	Correction (lbs/hr/acre)
50	0
100	0.5
150	0.8
200	1.2
300	2.0
400	4.0

[a] Interpolate for intermediate values not shown.

Table 2.4. (Contd.)

ZONE 3	
In unincorporated areas includes the M3 manufacturing district as established and defined in the Cook County Zoning Ordinance. In incorporated areas includes heavy manufacturing districts or the most intensive manufacturing districts as defined in the applicable local zoning ordinance.	
Particulate Matter	The rate of emission of particulate matter from all sources within the boundaries of any lot shall not exceed a net figure of 8 lb/acre during any one hour, after deducting from the gross hourly emission per acre the correction factor set forth in the following table:

Allowance for Height of Emission[a]

Height of Emission Above Grade (ft)	Correction (lbs/hr/acre)
50	0
100	0.5
150	1.5
200	2.4
300	4.0
400	8.0

[a] Interpolate for intermediate values not shown.

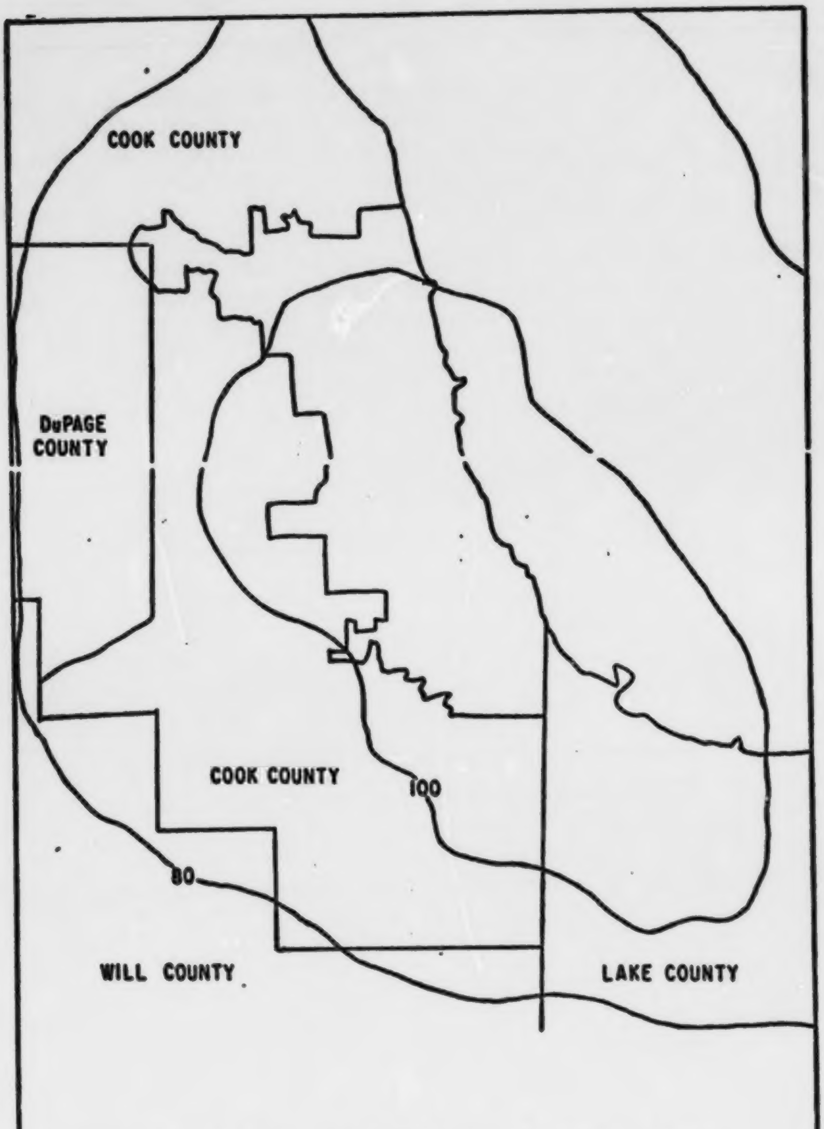


FIGURE 2.6. Chicago region suspended particulate isopleths with Cook County Ordinance and current land use

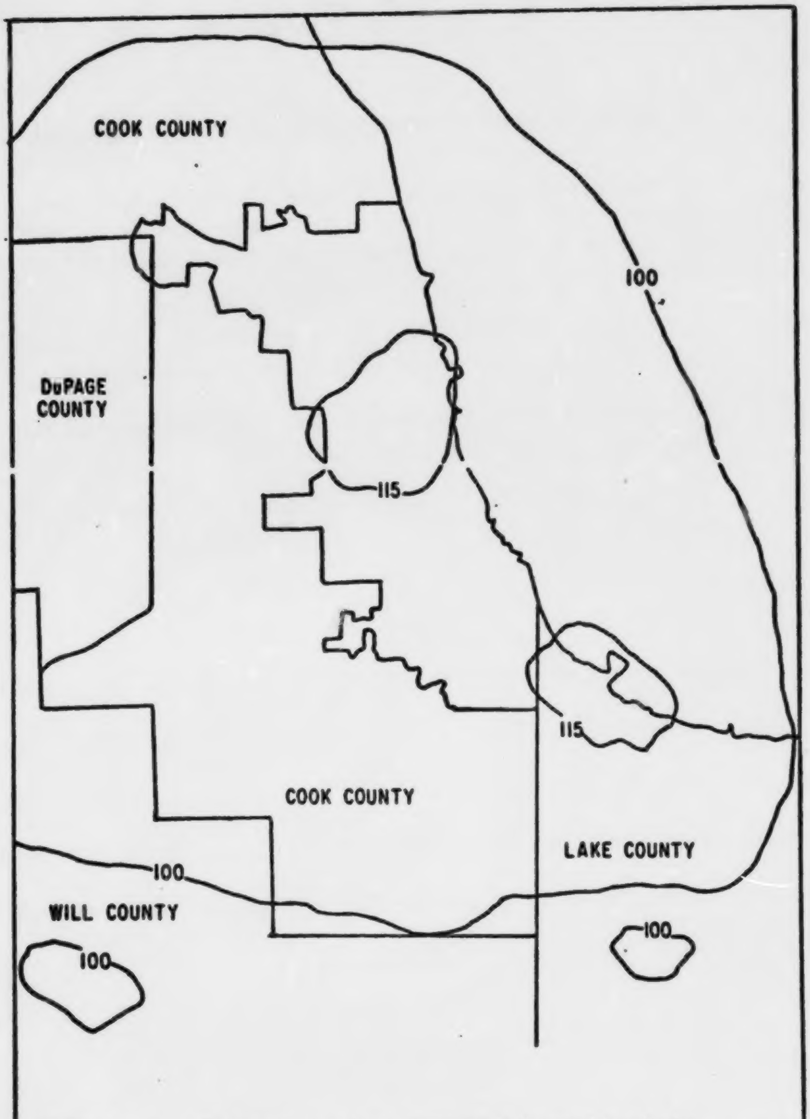


FIGURE 2.7. Chicago region suspended particulate isopleths with Cook County Ordinance and current zoned land

an index of land use or zoning class, then the pollutant concentration X_k at receptor point k, is given by

$$X_k = \sum_m \sum_\ell \alpha^m_{\ell k} \, ED^m_\ell \, A^m_\ell + \beta_k \qquad , \qquad (2.1)$$

where	X_k	is the pollutant concentration at receptor point k,
	$\alpha^m_{\ell k}$	is the dispersion model transfer coefficient describing the contribution of a unit emission from land use class m in grid square ℓ to the concentration at location k,
	ED^m_ℓ	represents the expected emission density in tons/day/mi^2 for land use class m in grid square ℓ,
	A^m_ℓ	is the specified percentage of land designated for land use class m in grid square ℓ,
	β_k	is the background concentration at receptor point k.

If it is further assumed that the emission density ED^m_ℓ is a policy variable to be set at some upper limit for control purposes, that this limit can vary by land use class m but is uniform over the entire region, and that $\hat{X}_k$ represents the standard (not necessarily uniform) at receptor point k, then the emission-density limits ED^m_ℓ are constrained as follows:

$$\hat{X}_k \geq \sum_m \sum_\ell \alpha^m_{\ell k} A^m_\ell ED^m_\ell + \beta_k \qquad (2.2)$$

or

$$\hat{X}_k \geq \sum_m ED^m_\ell \left\{ \sum_\ell \alpha^m_{\ell k} A^m_\ell \right\} + \beta_k \qquad (2.3)$$

or

$$\hat{X}_k \geq \sum P^m_k ED^m_\ell + \beta_k$$

where

$$P^m_k = \left\{ \sum_\ell \alpha^m_{\ell k} A^m_\ell \right\} .$$

The land use, A^m_ℓ, in each grid square ℓ devoted to class m can be either current land or a projected land use plan. In this study, both are utilized to test the effect of growth on the emission-density limits required to meet and maintain standards. Although a variable standard could be used, in this study $\hat{X}_k$ is assumed uniform throughout the region and $\hat{X}$ = 75 μg/m^3, the national standard.

When the current Chicago region manufacturing land use pattern is applied to Equation 2.1, many of the receptor points k are redundant. In fact, only two points are critical, as shown in Figure 2.8. These points correspond to the linear constraints comprising the limiting frontier shown in Figure 2.9. The intersection of these lines are points where both receptors are at the standard. Moving from this point along the boundary in the direction of increasing EDL^{LI} while decreasing EDL^{HI} will lower the concentration at critical receptor #2, while just maintaining the air quality standard at critical receptor #1; the opposite occurs if EDL^{HI} is increased while EDL^{LI} is decreased.

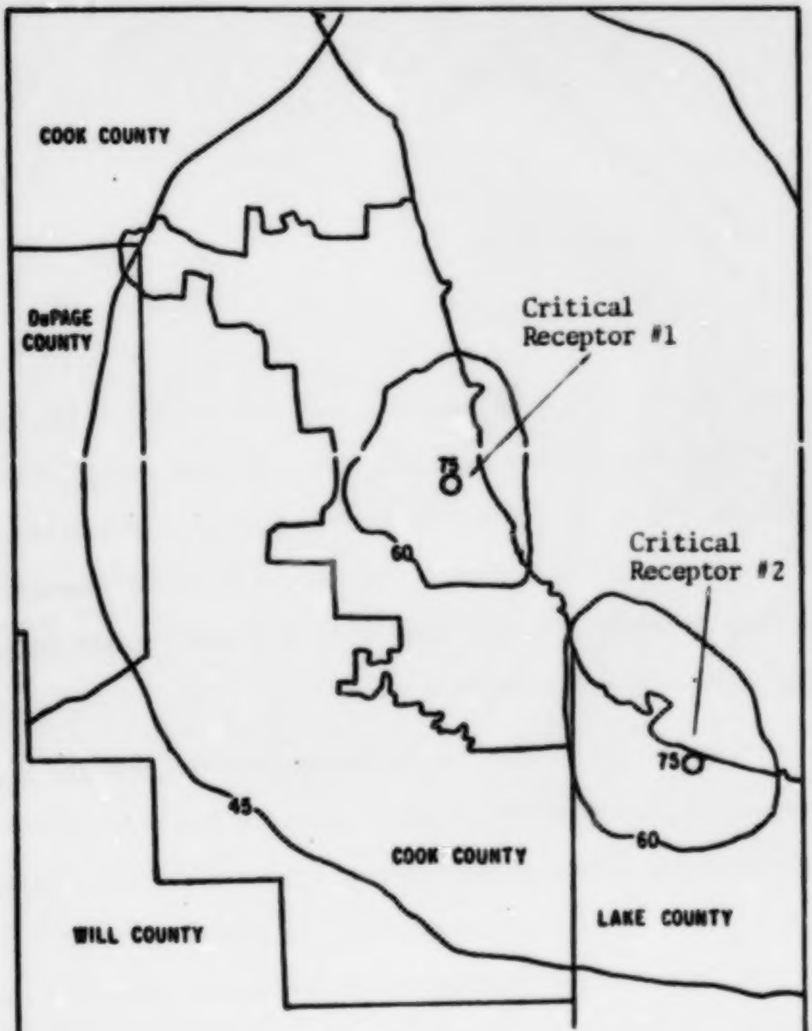


Figure 2.8. Chicago region suspended particulate isopleths with current land use and optimum emission-density limits ($EDL^{HI} = 3.3$ T/D/mi^2, $EDL^{LI} = 0.85$ T/D/mi^2)

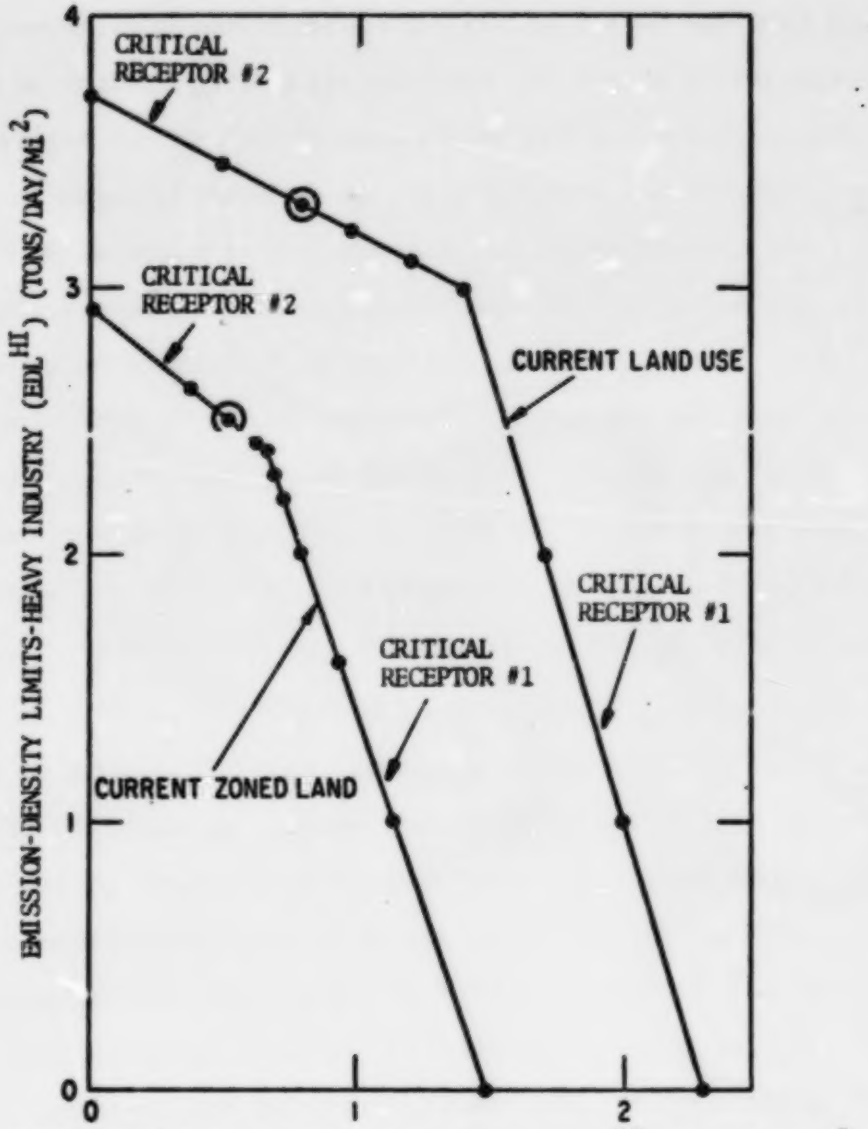


Figure 2.9. Air quality ($\mu g/m^3$ geometric mean) effectiveness frontier for suspended particulates using emission-density-limited zoning controls

A similar frontier is obtained when current zoned land is inserted into Equation 2.3, except the allowable limits frontier necessary to maintain air quality, assuming this development pattern will actually occur, is reduced. Figure 2.10 indicates the air quality degradation if the emission-density-limited zoning policy adopted just maintains air quality standards as growth occurs. Note in Figure 2.10 that the location of the critical receptors has shifted slightly from that in Figure 2.8. The pollutant isopleths in Figures 2.8 and 2.10 were calculated using the circled points on the frontiers for current land use and current zoned land, respectively, shown in Figure 2.9.

The linear frontier of Figure 2.9 determines an infinite set of emission density limits for heavy (EDL^{HI}) and light (EDL^{LI}) industrial land use that will achieve air quality. Criteria must be applied to select a unique pair of limits from this set. For this study, we have chosen to minimize the annualized cost incurred by existing sources for control devices that result from applying any pair of density limits on the frontier.

With emission-density limits enforced on the 475 selected sources for HI and LI, the percent reduction in particulate emissions required to achieve the limit can be calculated if land owned by the source operator is known. The control devices that meet the required reductions are selected for each SIC code, and the cost is calculated for the control equipment. The annualized cost is accumulated for each zoning class, and the optimum emission-density limits can be selected from the least annualized cost combination on the frontier. The results of applying this procedure to the Chicago source file are discussed in the next section.

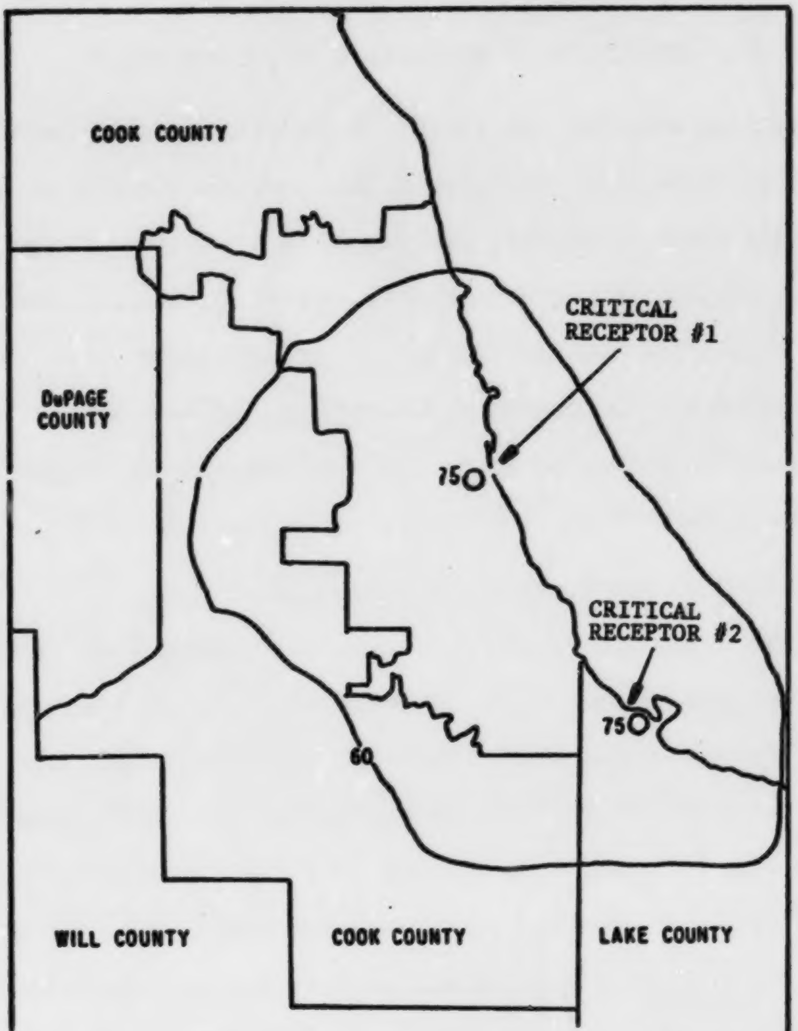


Figure 2.10 Chicago region suspended particulate isopleths with current zoned land and optimum emission-density limits (EDL^{HI} = 2.5 T/D/mi^2, EDL^{LI} = 0.55 T/D/Mi^2)

3.0 APPLICATION OF METHODOLOGY TO CHICAGO REGION

This section describes the results of applying the above methodology to the Chicago study area. Included in this area are the City of Chicago itself and the three surrounding counties of Cook (outside Chicago), Will and DuPage. The two methods of achieving ambient air quality standards, point-source controls, and emission-density zoning, are examined on a cost-effectiveness basis. The results are summarized for two-digit SIC codes, heavy and light manufacturing zones, and total manufacturing. The sensitivity of the results to permited-use zoning policies are tested.

3.1 COST OF CONTROL FOR POINT-SOURCE REGULATION

The State of Illinois particulate control regulations were used for comparison purposes in this study. Process emissions are limited by a "Bay Area" type of regulation as a function of process weight rate. Fuel combustion emissions are regulated as a proportion of BTU (heating value) input. The details of these regulations are discussed in Appendix A.

In calculating the cost of particulate emission control for Chicago, the device comprising the least annualized cost for each individual source is selected, and a total annualized cost for the point-source control strategy is calculated from the summation of individual source costs. In operating the various types of control equipment, the commodities of water, power, and fuel are used; the consumption and costs of these resources are also calculated. When the standard industrial classification codes are grouped into light and heavy industry, the annualized costs of point-source control (PSC) are shown in Table 3.1. The total annualized cost for PSC was 1.393 million dollars for the 475 sources, with heavy industry contributing approximately 75% of the cost and light industry, approximately 25%. The resources required and costs accrued in operating these control devices can also be seen in Table 3.1 for the zoning classification, and in Table 3.2 for the standard industrial classification. The SIC classes 28 and 32, which contribute the greatest cost, constitute 40% of the total annualized cost of control for the Illinois portion of the Metropolitan Chicago Interstate Interstate Air Quality Control Region. In the operational cost of the equipment, the power cost of operating the equipment contributes 34% of the total annualized cost, fuel for operating after-burners contributes 10%, and water utilized in operating wet scrubbers constitutes 0.1% of the total annualized cost. The power cost is distributed evenly over the SIC classification, while the fuel and water costs predominate in the SIC codes classes as heavy industry.

3.2 EFFECTIVENESS OF POINT-SOURCE CONTROL

When the Illinois point-source regulations were applied to the individual sources in the regional data file, the reductions in particulate emissions ranged from 78% in SIC 20 (the food and kindred industries) to 99% in SIC 27 (the printing and publishing industries). As can be seen in Table 3.3, the particulate emissions resulting after control techniques have been applied range from 0.01 tons/day for industries in the light industrial classification to 0.31 tons/days in the petroleum and coal industries. The regulation favors industry with large process weight where the average emissions after control are 0.09 tons/day, while the industries with small process weight emit 0.02 tons/day after control.

Table 3.1. ANNUAL POINT-SOURCE CONTROL AND UTILITY COSTS BY STANDARD LAND USE CLASSIFICATION

SLUC	ANNUAL COST ($/YR)	POWER USE (MW/YR)	POWER COST ($/YR)	FUEL COST ($/YR)	WATER USE (GAL/YR)	WATER COST ($/YR)
HI	998369	21933	364211	145744	1168408	891
LI	394640	7583	113739	0	30748	22
TOTAL	1,393009	29516	477950	145744	1,199156	913

HI=26-33
LI=20-25, 34-39

Table 3.2. ANNUAL POINT-SOURCE CONTROL AND UTILITY COSTS BY STANDARD INDUSTRIAL CLASSIFICATION

SIC	ANNUAL COST ($/YR)	POWER USE (MW/YR)	POWER COST ($/YR)	FUEL COST ($/YR)	WATER USE (GAL/YR)	WATER COST ($/YR)
20	78441	2790	41846	0	0	0
21	0	0	0	0	0	0
22	1145	12	175	0	0	0
23	1435	15	220	0	0	0
24	26615	315	4721	0	0	0
25	26998	450	6752	0	0	0
26	42464	479	7186	0	0	0
27	78734	818	12269	48581	30748	21
28	408742	9703	160763	97162	737942	590
29	113256	2733	40990	0	30748	22
30	14401	342	5136	0	30748	22
31	0	0	0	0	0	0
32	166798	4275	64125	0	30748	22
33	93065	2143	32149	0	245991	172
34	80909	1440	21593	0	61495	43
35	118611	1584	23758	0	0	0
36	73043	1225	18372	0	0	0
37	26689	578	8668	0	0	0
38	15437	338	5072	0	30748	22
39	25825	277	4155	0	0	0

HI = SIC 26-33
LI = Remaining SIC's

Table 3.3. POINT-SOURCE CONTROL REGULATIONS APPLIED TO THE CHICAGO REGION

		Emissions (tons/day)	Point Source Control Required Reduction (percent)	Point Source Control Required Reductions (tons/day)	Emissions After Control (tons/day)
20	Food and kindred	0.14	78	0.11	0.03
22	Textile mills	0.48	92	0.44	0.04
24	Lumber and wood	0.13	95	0.12	0.01
25	Furniture and fixtures	0.08	85	0.07	0.01
26	Paper and allied	0.48	91	0.43	0.05
27	Printing and publishing	0.40	99	0.39	0.01
28	Chemicals and allied	1.03	87	0.89	0.13
29	Petroleum and coal	2.23	87	1.92	0.31
30	Rubber and plastics	0.22	88	0.19	0.03
32	Stone, clay, and glass	1.20	94	1.12	0.08
33	Primary metals	0.47	91	0.42	0.05
34	Fabricated metal	0.37	93	0.34	0.04
35	Machinery, non-electrical	0.52	92	0.48	0.04
36	Machinery, electrical	0.25	90	0.23	0.02
37	Transportation equipment	0.34	93	0.31	0.03
38	Instruments and related	0.12	90	0.10	0.02
39	Misc. manufacturing	0.19	97	0.18	0.01

HI = SIC 26-33
LI = Remaining SICs

Figure 2.4 in Section 2, which depicts the total suspended particulate isopleths with Illinois point-source control regulations, shows that the standard of 75 $\mu g/m^3$ is achieved with the Illinois regulation. However, the air quality is such that a significant portion of the City of Chicago and the northern Indiana regions are at, or near, the maximum allowable concentration, while the outlying residential areas and suburbs are below the national and state standards. Industrial development in the southern and southwestern portions of the region could again threaten standards even with point-source controls applied unless maintenance measures are enacted.

3.3 DETERMINATION OF LEAST-COST EMISSION-DENSITY LIMITS FOR THE CHICAGO REGION

To determine the least-cost combination of heavy industrial and light industrial emission-density limits (EDL^{HI} and EDL^{LI}, respectively) in the Chicago region that satisfy the national ambient air quality standard of 75 $\mu g/m^3$, the procedure as outlined in Section 2 was followed. Several combinations of limits were calculated on the boundary frontier as shown in Figure 2.9. Table 3.4 shows the results of these calculations.

The least-cost combination for current land use occurs when heavy industrial emission-density limits are set at 3.3 tons/day/mi^2 and light industrial emission limits are set at 0.85 tons/day/mi^2. For current zoned land, the optimum combination of emission-density limits for heavy industry is 2.5 tons/day/mi^2 and 0.55 tons/day/mi^2 for light industry. The density limits should be set at the latter levels when the land is developed under planned zoning to ensure that ambient air standards are met as growth occurs. The least-cost emission-density limits are shown as the circled points on the boundary of Figure 2.9.

Table 3.4. LEAST-COST COMBINATION OF EMISSION-DENSITY LIMITS

CURRENT LAND USE				
Emission Density Limits in Tons/Day/Mi^2		Annualized Cost in 10^6 Dollars		
EDL^{HI}	EDL^{LI}	EDL^{HI}	EDL^{LI}	EDL^{TOTAL}
3.7	.001	1.017	0.657	1.674
3.4	.5	1.044	0.444	1.488
3.3*	.85	1.044	0.408	1.452
3.2	1.0	1.054	0.404	1.458
3.1	1.3	1.068	0.399	1.467
3.0	1.4	1.086	0.398	1.484
2.0	1.7	1.169	0.395	1.564
1.0	2.0	1.487	0.373	1.860
0.	2.3	2.344	0.365	2.709

CURRENT ZONED LAND				
Emission Density Limits in Tons/Day/Mi^2		Annualized Cost in 10^6 Dollars		
EDL^{HI}	EDL^{LI}	EDL^{HI}	EDL^{LI}	EDL^{TOTAL}
2.9	.001	1.090	0.490	1.580
2.6	.4	1.100	0.451	1.551
2.5*	.55	1.098	0.438	1.535
2.4	.66	1.104	0.431	1.535
2.3	.7	1.115	0.429	1.544
2.2	.78	1.128	0.421	1.549
2.0	.8	1.169	0.415	1.584
1.0	1.14	1.487	0.405	1.892
0.	1.5	2.563	0.397	2.960

*Denotes least cost combination

HI = 26-33
LI = 20-25, 34-39

3.4 THE COST OF CONTROL FOR EMISSION-DENSITY ZONING

The cost of controlling emissions to the limits set by the least-cost emission-density regulations determined above are presented in this section. It is assumed that the source operator will put on a control device, rather than buy more land to satisfy the regulation.

From Table 3.5, the total annual cost for EDLZ to achieve the national particulate ambient air standard at present land use is $1.452 million. When the current zoned but undeveloped land is included in the land use inventory, the cost rises to $1.535 million to maintain the national standard as growth occurs. Tables 3.6 and 3.7 represent the annualized and utility costs for current land use and current zoned land by SIC, respectively, for the 475 selected sources. The utility costs follow the same pattern for both the present land use and current zoned land, as for point-source control. Power, water, and fuel costs predominate in the heavy industrial category.

3.5 EFFECTIVENESS OF EMISSION-DENSITY ZONING

Emission-density limits were applied to the 475 sources in the Chicago region; the reductions achieved can be seen in Table 3.8. The EDLZ efficiency ranged from 45% in the SIC code 38 (instrument and related) to 99% in SIC 27 (printing and publishing). This variance is due to the amount of land per source and the emissions emanating from the source. In SIC 38, the emissions are small and the land size is large; therefore, the required reductions are low. On the other hand, in SIC 27, the emissions are high, while the land size is small, requiring maximum control.

The least-cost emission-density limits have been selected to achieve and maintain air quality standards and are therefore effective by definition.

Table 3.5. EDLZ ANNUAL CONTROL AND UTILITY COSTS
BY ZONING USE CLASSIFICATION

SLUC			Current Land Use $(EDL^{HI}=3.3\ T/D/Mi^2,\ EDL^{LI}=0.85\ T/D/Mi^2)$			
	ANNUAL COST ($/YR)	POWER USE (MW/YR)	POWER COST ($/YR)	FUEL COST ($/YR)	WATER USE (GAL/YR)	WATER COST ($/YR)
HI	1044030	27364	419270	145744	1383641	986
LI	408251	7016	105242	0	0	0
TOTALS	1,452281	34380	524512	145744	1,383641	986

SLUC			Current Zoned Land $(EDL^{HI}=2.5\ T/D/Mi^2,\ EDL^{LI}=0.55\ T/D/Mi^2)$			
	ANNUAL COST ($/YR)	POWER USE (MW/YR)	POWER COST ($/YR)	FUEL COST ($/YR)	WATER USE (GAL/YR)	WATER COST ($/YR)
HI	1097731	28258	432679	145744	1660369	1180
LI	437535	6647	99705	0	30748	22
TOTALS	1,535266	34905	532384	145744	1,691117	1202

HI = 26-33
LI = 20-25, 34-39

Table 3.6. CURRENT LAND USE EDLZ ANNUAL CONTROL AND UTILITY COSTS BY STANDARD INDUSTRIAL CLASSIFICATION ($EDL^{HI}=3.3\ T/D/Mi^2$, $EDL^{LI}=0.85\ T/D/Mi^2$)

SIC	ANNUAL COST ($/YR)	POWER USE (MW, YR)	POWER COST ($/YR)	FUEL COST ($/YR)	WATER USE (GAL/YR)	WATER COST ($/YR)
20	114133	1941	29110	0	0	0
21	0	0	0	0	0	0
22	3211	85	1275	0	0	0
23	0	0	0	0	0	0
24	20744	322	4830	0	0	0
25	21577	271	4061	0	0	0
26	51165	1114	16715	0	245981	172
27	76929	848	12722	48581	30748	21
28	306967	6637	95551	97162	522709	365
29	148071	6216	93245	0	215233	151
30	12102	330	4957	0	0	0
31	0	0	0	0	0	0
32	245580	7697	124259	0	122990	105
33	120743	2764	41464	0	184485	129
34	82472	1757	26356	0	61495	43
35	121043	1978	28164	0	0	0
36	75237	1318	19769	0	0	0
37	21983	659	9891	0	0	0
38	8543	122	1834	0	0	0
39	21730	420	6306	0	0	0

HI = 26-33
LI = 20-25, 34-39

Table 3.7. CURRENT ZONED LAND EDLZ ANNUAL CONTROL AND UTILITY COSTS BY STANDARD INDUSTRIAL CLASSIFICATION ($EDL^{HI}=2.5$ T/D/Mi^2, $EDL^{LI}=0.55$ T/D/Mi^2)

SIC	ANNUAL COST ($/YR)	POWER USE (MW YR)	POWER COST ($/YR)	FUEL COST ($/YR)	WATER USE (GAL/YR)	WATER COST ($/YR)
20	118580	2013	30192	0	0	0
21	0	0	0	0	0	0
22	3385	85	1275	0	0	0
23	0	0	0	0	0	0
24	18869	296	4442	0	0	0
25	26592	365	5474	0	0	0
26	63517	1432	21478	0	245981	172
27	77458	878	13173	48581	30748	21
28	335509	7425	111370	97162	584204	408
29	161437	6827	102339	0	338223	237
30	12226	330	4957	0	0	0
31	0	0	0	0	0	0
32	229333	6580	107500	0	61495	61
33	130932	2948	44220	0	338223	237
34	87319	1838	27582	0	61495	43
35	130685	1613	24201	0	0	0
36	77429	1165	17479	0	0	0
37	23626	494	7410	0	0	0
38	16510	268	4021	0	30748	22
39	21860	347	5209	0	0	0

HI = 26-33
LI = 20-25, 34-39

Table 3.8. EDLZ REGULATIONS APPLIED TO THE CHICAGO REGION

		Emissions (tons/day)	EDLZ Required Reduction (percent)	EDLZ Required Reduction (tons/day)	Emissions After Control (tons/day)
20	Food and kindred	0.14	88	0.12	0.02
22	Textile mills	0.48	96	0.46	0.02
24	Lumber and wood	0.13	94	0.12	0.01
25	Furniture and fixtures	0.08	82	0.06	0.02
26	Paper and allied	0.48	90	0.46	0.02
27	Printing and publishing	0.40	99	0.39	0.01
28	Chemicals and allied	1.03	52	0.54	0.49
29	Petroleum and coal	2.23	82	1.83	0.40
30	Rubber and plastics	0.22	87	0.19	0.03
32	Stone, clay, and glass	1.20	96	1.15	0.05
33	Primary metals	0.47	94	0.44	0.03
34	Fabricated metal	0.37	92	0.34	0.03
35	Machinery, non-electrical	0.52	88	0.46	0.06
36	Machinery, electrical	0.25	80	0.20	0.05
37	Transportation equipment	0.34	79	0.26	0.08
38	Instruments and related	0.12	45	0.05	0.07
39	Misc. manufacturing	0.19	92	0.17	0.02

HI=SIC 26-33
LI=Remaining SIC

The pollution concentration isopleths shown in Figures 2.8 and 2.10 of Section 2 are the results of controlling for current manufacturing land use and zoned (but not necessarily, used) land, respectively. The results of the previous section indicate that the incremental annual cost to industry to achieve air quality maintenance as development occurs is approximately $80,000 or 5.5% over current land use control costs.

3.6 COMPARISON OF POINT-SOURCE CONTROL AND EMISSION-DENSITY-LIMITED ZONING

This section brings together the results of the previous sections for purposes of comparing the two approaches to air quality regulation. The relevant pollution concentration isopleth maps for point-source control are shown in Figure 2.4, and for emission-density-limited zoning in Figures 2.8 and 2.10. The resulting average concentrations, using point-source control and emission-density limits applied to current manufacturing land use, yield roughly equivalent results. If the emission-density limits derived from current zoned land use patterns are used, current air quality would be considerably improved, as shown in Figure 3.1. However, air quality would continue to degrade as growth occurred with the maximum possible degradation, as indicated in Figure 2.10, assuming the growth pattern follows the zoning process. This may be preferable to uncontrolled growth, however, since degradation cannot be predicted accurately on a regional basis without setting some form of limitation on allowed densities.

Both types of regulations were applied to the point-sources in the Chicago region. A comparison of the required emission reductions by 2-digit SIC code for both types of regulations is presented in Figures 3.2 and 3.3. The two strategies require approximately the same degree of control for all

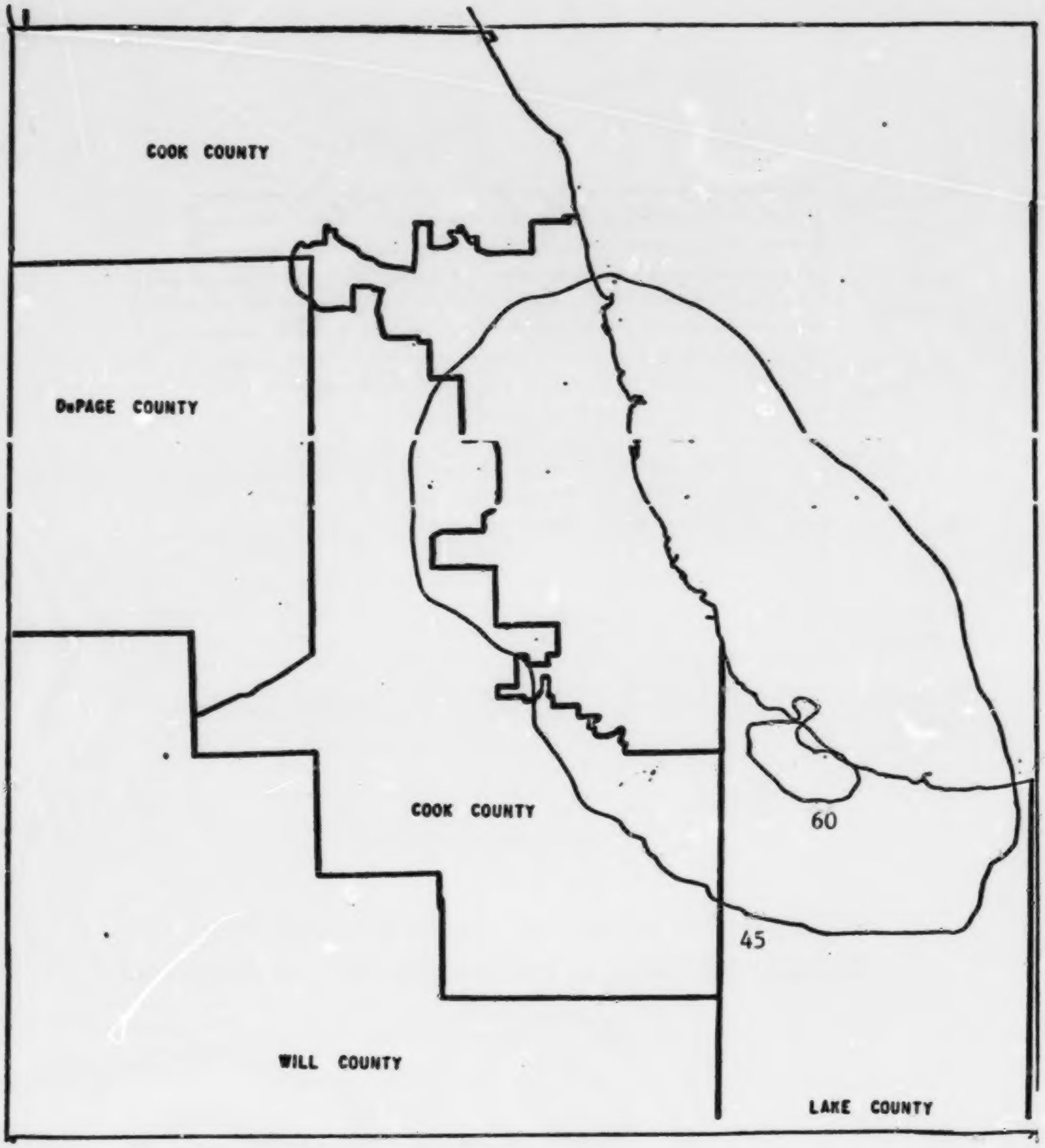


Figure 3.1. Chicago region suspended particulate isopleths with current land use and optimum emission-density limits for current zoned land (EDL^{HI}=2.5 T/D/Mi^2, EDL^{LI}=0.55 T/D/Mi^2)

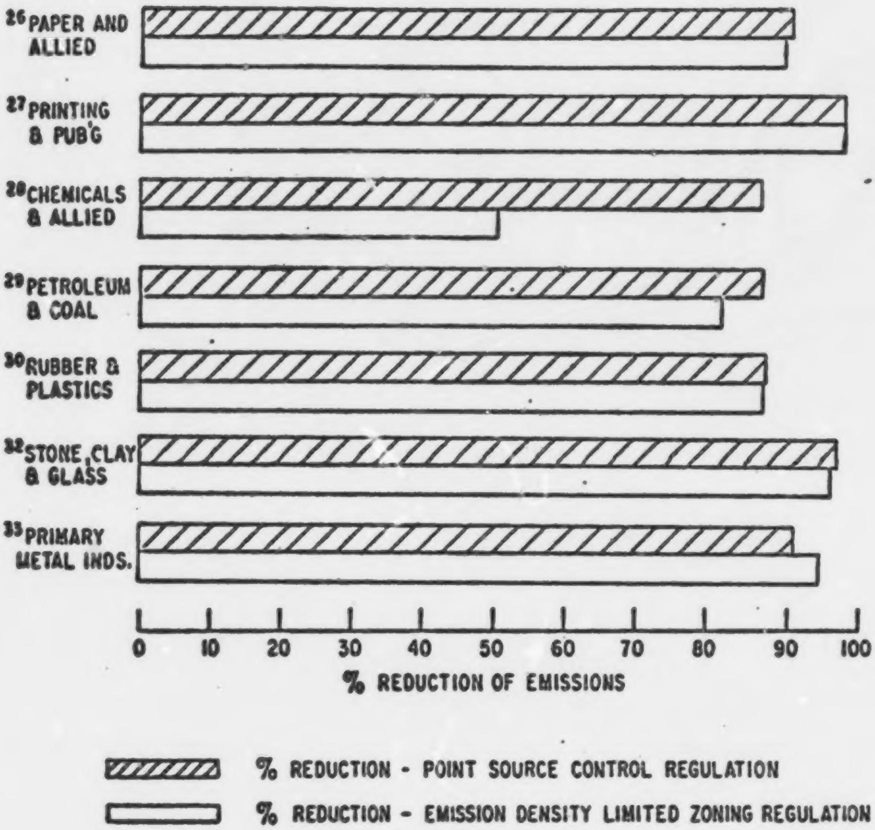


Figure 3.2. Comparison of reduction required by the strategies for heavy industry

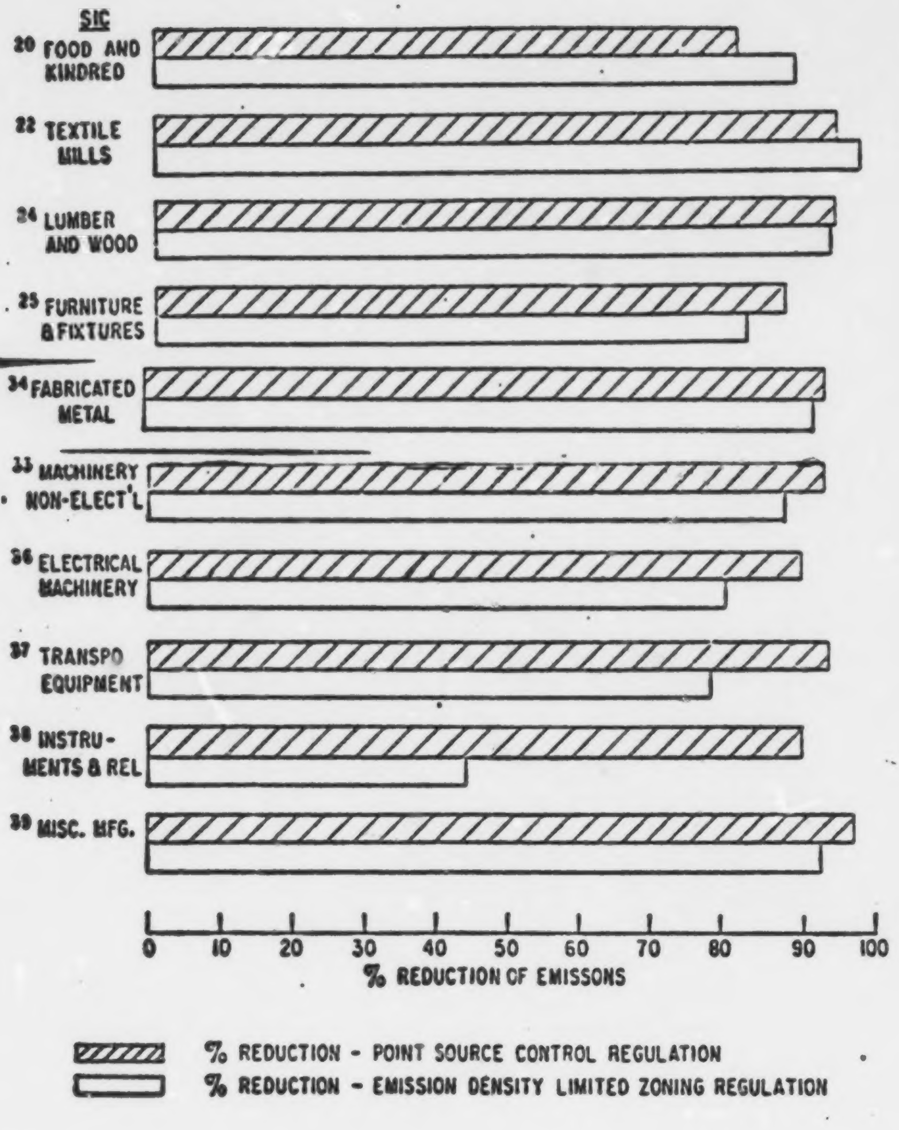


Figure 3.3. Comparison of reduction required by the strategies for light industry

SIC classes, except SIC 28 (chemicals and allied) and SIC 38 (instruments and related). The EDLZ required efficiency is much less for these SIC codes because the industries in these classes have a large amount of land over which to distribute their emissions.

The costs associated with achieving these reductions are presented in Figure 3.4. The PSC and EDLZ costs vary by SIC, but, for the most part, the strategies do not differ greatly in cost. As a result, EDLZ is an effective long-range control that is only slightly more costly (10%) than PSC, assuming a stable zoning process. This is further substantiated by Figure 3.5 which shows the costs by standard land use classification along with the associated utility cost. EDLZ is slightly greater in cost, with heavy industry having the added expense of water and fuel. From these figures, it can be seen that EDLZ is an economic control strategy in achieving and maintaining ambient air quality.

3.7 SENSITIVITY OF RESULTS TO PERMITTED-USE ZONING POLICY

The sensitivity of the results to permitted-use zoning policy was tested on the same emission-density boundary frontier (Figure 2.9) with the current zoned land use inventory. The sources with activities in SIC codes 29, 32 and 33 were classed as heavy industry, while the remainder of the SIC codes from 20-39 were classed as light industry. This group was selected for the heavy industrial classification because these three classes account for 63 percent of the total suspended particulates and constitute approximately one-third of the sources in the region, as seen in Table 3.9.

In order to formulate a least-cost combination of emission-density limits for this activity grouping, several combinations of limits were

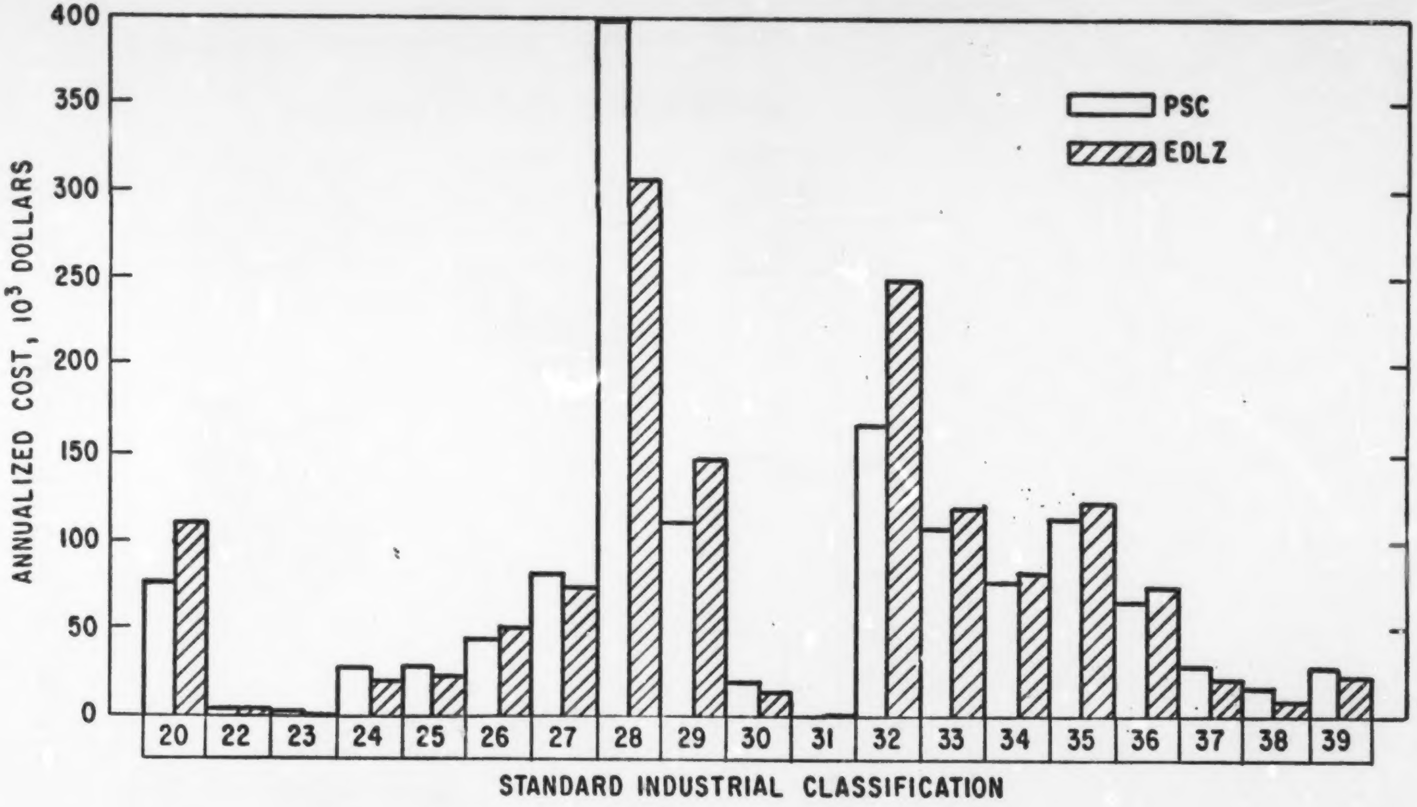


Figure 3.4. Annualized cost comparison of the strategies by SIC

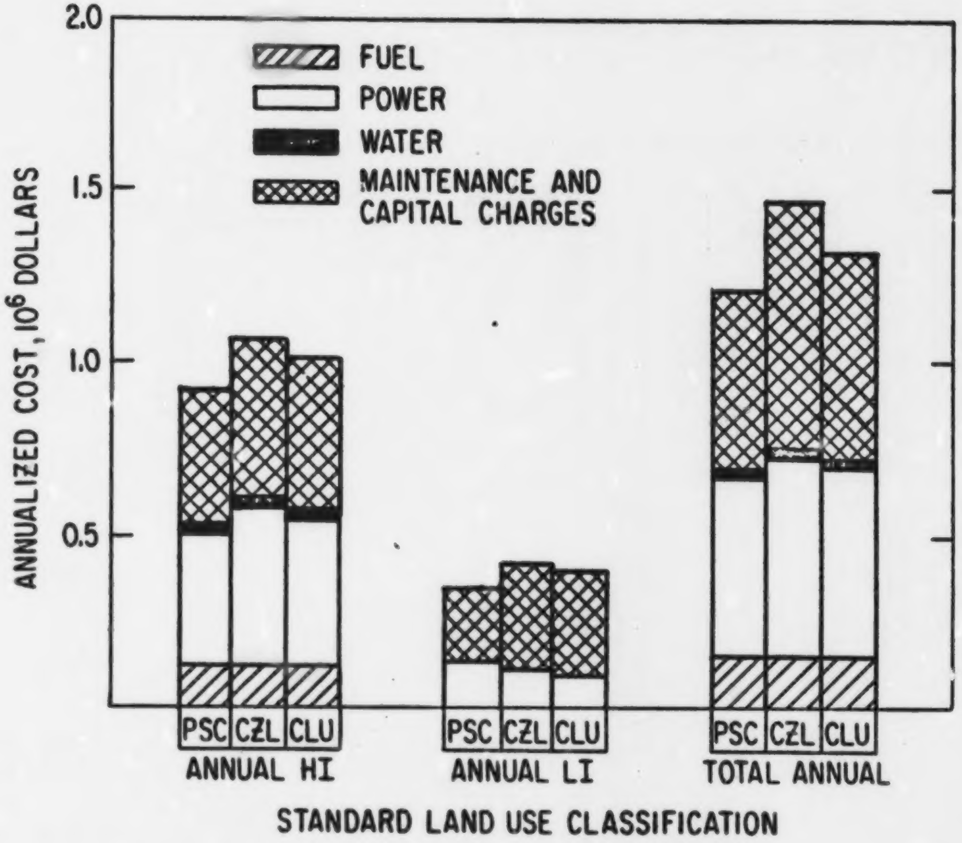


Figure 3.5. Annualized cost comparison of the strategies by SLUC

Table 3.9. PERCENT OF SUSPENDED PARTICULATES EMITTED BY THE THREE LARGEST SIC CLASSES IN THE REGION

SIC	% of TSP	Number of Sources
32	29.4	50
29	17.0	40
33	16.2	83
TOTAL	62.6	173

calculated on the boundary frontier, as shown in Table 3.10. The least-cost combination is seen to be at the emission-density limits of 2.2 tons/day/mi^2 for heavy industry and 0.78 tons/day/mi^2 for light industry. These optimal limits for the permitted-use zoning constrain the heavy industry activities and are less stringent on the light industry activities, as compared to the more traditional method of classifying heavy industry as SIC 26-33 and light industry as 20-25 and 34-39. The optimal annual cost associated with the modified permitted-use zoning policy is 1.78 million dollars,as compared to the 1.54 million dollar cost with the more traditional zoning policy.

Table 3.10. LEAST-COST COMBINATION OF EMISSION-DENSITY LIMITS FOR PERMITTED-USE ZONING

Current Zoned Land

Emission-density limits in tons/day/mi^2		Annualized cost in 10^6 Dollars		
EDL^{HI}	EDL^{LI}	EDL^{HI}	EDL^{LI}	Total EDL
2.9	0.001	0.529	1.893	2.422
2.6	0.4	0.524	1.437	1.961
2.5*	0.55	0.522	1.333	1.855
2.4	0.66	0.530	1.316	1.846
2.3	0.7	0.539	1.309	1.848
2.2†	0.78	0.555	1.227	1.782
2.0	0.8	0.576	1.219	1.795
1.0	1.14	0.690	1.184	1.874
0.001	1.5	0.856	1.458	2.314

* Traditional zoning optimum
† Permitted-use zoning optimum

HI = 29,32,33
LI = 20-28, 30-31, 34-39

4.0 SUMMARY AND CONCLUSION

The system model that was developed for this study compared and evaluated two emission control approaches, point-source control and emission-density-limited zoning. This model was successfully tested using a data base including 475 selected process and fuel combustion sources from a three-county region in the Chicago metropolitan area. The two approaches were compared for particulate control on a cost-effectiveness basis, using annualized cost as the criterian. The model can be expanded to include other approaches. Also, additional pollutants can be investigated by programming applicable control devices into the model as appropriate.

The following conclusions are drawn from this study:

1) Emission-density-limited zoning and point-source control regulations are equally effective strategies for achieving the national particulate matter air quality standards in the Chicago region by 1975.

2) An emission-density-limited zoning policy sets an upper limit on the amount of deterioration in air quality in the region if the density limits are established to include land zoned for manufacturing development as well as current developed land.

This is so virtually by the definition of the density limitations, if they have been established to meet air quality standards and are based on a stable zoning policy that reflects comprehensive planning in the region.

3) An emission-density-limited zoning policy established to account for planned regional development has the potential advantage of achieving a better overall average air pollution concentration in the short run (1975) than do the present point-source control regulations, at the expense of a slightly increased annual control cost of 10%, or $140,000, for the 475 sources selected for this study.

4) Point-source control regulations are quite stringent in an economic sense for sources with a combination of large process weight rate and large emission factors, and are lenient for sources with small emission factors and large process weight. The total annualized cost for point-source control with the 475 selected industries in the Chicago metropolitan area was 1.393 million dollars, with heavy industry contributing approximately 75 percent of the cost and light industry 25 percent.

5) In delineation of the total annualized cost, capital and maintenance charges constitute approximately 56 percent, power costs of operating the equipment contribute 34 percent,

fuel for operating afterburners contributes 10 percent, and water utilized in operating wet scrubbers constitutes 0.1 percent. The power cost is distributed evenly over the SIC classes, while the fuel and water costs predominate in the heavy industrial category.

6) A least-cost emission-density limited zoning policy was formulated in order for air quality to be achieved throughout the Chicago region. The least-cost EDLZ limits were found to be 3.3 tons/day/mi^2 for heavy industry and 0.85 tons/day/mi^2 for light industry, based on present manufacturing land use. When the current zoned land inventory was included, the limits decreased to 2.5 tons/day/mi^2 for heavy industry and 0.55 tons/day/mi^2 for light industry.

7) The total annual cost for 475 selected industries with EDLZ based on present land use is 1.452 million dollars. When the current zoned land is included, the cost rises to 1.535 million dollars. The associated costs follow the same pattern as for point-source control. The division of total control costs between heavy and light industry is also roughly the same (HI-75%, LI-25%).

8) The point-source control and EDLZ approaches do not differ greatly in cost or resource utilization; as a result, ELDZ is a potentially viable economic control for achieving and maintaining ambient air quality.

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2. Martin, D. and Tickvart, J. A General Atmospheric Diffusion Model for Estimating the Effects of Air Quality of One or More Sources. APCA paper. June 1968.

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APPENDIX A

LITERATURE REVIEW

Air Pollution Source Control Regulation, Particulate Emission Control Devices, and the Air Pollution-Land Use Interface

APPENDIX A LITERATURE REVIEW

A review of the literature was conducted to learn to what extent cost-effectiveness type studies have been used in analysis of alternate control approaches for particulate pollution control. In large urban areas, a reduction in emissions must usually be accomplished in order to achieve the federal ambient air quality standards. That legislation enacted to effect reduction in emissions for particulate matter was studied. After studying the federal and state regulations, we reviewed control equipment to determine the types of control devices that meet the required reductions and the technical requirements of each Standard Industrial Classification (SIC) Code. The cost of control equipment that meets these objectives was analyzed by type of control device and by variation of control devices by industry. Finally, studies that have attempted to link air pollution and land use are reviewed.

A.1 LEGISLATION REGARDING AIR POLLUTION CONTROL FOR PARTICULATE MATTER

The development of environmental protection and enhancement measures in the United States has been, for the most part, determined by state and federal legislation.

A.1.1 Federal Legislation

Air quality legislation enacted by the federal government began in July 1955, when Congress authorized a program of research and technical assistance to state and local governments. The period from 1963 to 1970 produced the most significant legislation regarding air quality: the Clean Air Act of 1963, the Motor Vehicle Act of 1965, the Air Quality Act of 1967, and the culminating Clean Air Act Amendments of 1970. The 1970 Amendments, characterized as currently the strongest air pollution control legislation, authorize the regulation of both mobile and stationary sources of pollution. These programs deal with establishing national air quality standards, describing a framework for the state to meet these standards, and improving procedures for federal enforcement. National ambient air quality standards for particulate matter, sulfur oxides, carbon monoxide, photochemical oxidants, hydrocarbons, and nitrogen oxides have thus far been promulgated by the Environmental Protection Agency. Federal guidelines published by the EPA require that states submit implementation plans for the attainment and maintenance of these standards.[1]

The 1970 amendments also provide for more effective federal enforcement by allowing the EPA to issue compliance orders to any person violating applicable implementation plans or to bring civil suit against any person in violation of implementation plans; they also authorize citizen suits to enforce the provisions of the Clean Air Act.

The Clean Air Amendments are an example of a recent shift in the burden of proof in pollution control. When the EPA now specifies that an air pollutant is a health hazard, industry must either comply with the emission standard or prove that the health hazard does not exist.[1]

A.1.2 State Legislation

In implementing the federal guidelines for the State of Illinois, the Illinois Pollution Control Board adopted a set of comprehensive air pollution control regulations designed to limit emissions of sulfur dioxide, particulate matter, nitrogen oxides, carbon monoxide, and hydrocarbons from stationary sources throughout Illinois.[5]

An additional provision that would have effectively banned coal for residential or commercial use in the Chicago area by mid-1975 was not included in the package due to a temporary restraining order. This order was entered against the Board by a Cook County Circuit Court Judge, who termed the ban unconstitutional as presently structured.

The new regulations represent a major effort by the state to control the air contaminants, and form the heart of the Illinois program to meet the federal standards and to combat air pollution. Except for controls on particulate matter, the state previously did not have emission limits on these air pollutants.[5]

Specifically, in regard to particulate air contaminants, the program:

1) Significantly tightens limits on the emission of particulate matter from such operations as steel mills, oil refineries, electric power plants, cement plants, and corn wet-milling facilities.

2) For the first time, requires sophisticated new equipment to control emissions from coke ovens.

3) Greatly strengthens existing standards for emissions from incinerators.

4) Adopts a statewide nondegradation standard to prevent the unnecessary deterioration of air that is now clean, and to prevent new sources of pollution from being located in inappropriate places.

5) Institutes a statewide requirement of operating permits for all pollution sources as an aid to enforcement.

6) Requires sources to monitor their emissions, to keep detailed records, to adequately maintain their equipment, and to make regular reports to the state.

7) Specifies particulate emission standards and limitations for new and existing emission sources, for incinerators, and for fuel combustion emission sources.

The air pollution regulations are designed to enable the state to meet the national ambient air quality standard by 1975.[5]

In the case of Illinois manufacturing sources, emission standards are divided into fuel combustion and process regulations. Fuel emission regulations in the Chicago major metropolitan area require that no person shall cause or allow the emission of particulate matter into the atmosphere from any existing fuel combustion source to exceed 0.1 pound of particulate matter per million Btu of actual heat input in any one-hour period.[5]

For process emission sources, no person shall cause or allow the emission of particulate matter into the atmosphere in any one-hour period from any existing process emission source in excess of the allowable emission rates specified in Table A.1, either alone or in combination with the emission of particulate matter from all other similar new or existing process emission sources at a plant or premises. Interpolated and extrapolated values of the numbers in Table A.1 for process weight rates up to 30 tons per hour shall be determined by using the equation.[5]

$$E = 4.10\ (P)^{0.67} \quad , \qquad \text{(A.1)}$$

Table A.1. ILLINOIS STANDARDS FOR EXISTING PROCESS EMISSION SOURCES

Process Weight Rate Pounds Per Hour	Process Weight Rate Tons Per Hour	Allowable Emission Rate Pounds Per Hour
100	0.05	0.55
200	0.10	0.87
400	0.20	1.40
600	0.30	1.83
800	0.40	2.22
1,000	0.50	2.58
1,500	0.75	3.38
2.000	1.00	4.10
4,000	2.00	6.52
6,000	3.00	8.56
8,000	4.00	10.40
10,000	5.00	12.00
20,000	10.00	19.20
30,000	15.00	25.20
40,000	20.00	30.50
50,000	25.00	35.40
60,000	30.00	40.00
70,000	35.00	41.30
80,000	40.00	42.50
90,000	45.00	43.60
100,000	50.00	44.60
200,000	100.00	51.20
300,000	150.00	55.40
400,000	200.00	58.60
500,000	250.00	61.00
600,000	300.00	63.10
700,000	350.00	64.90
800,000	400.00	66.20
900,000	450.00	67.70
1,000,000	500.00	69.00

Source: State of Illinois Air Pollution Control Implementation Plan. II. December 1971.

and interpolated and extrapolated values of the data for process weight rates in excess of 30 tons per hour shall be determined by using the equation:

$$E = \left[55.0\ (P)^{0.11}\right] - 40.0 \quad , \qquad (A.2)$$

where E = allowable emission rate in pounds per hour

and P = process weight rate in tons per hour.

The process weight regulation in the Illinois Implementation Plan was modeled after the Bay Area Curve developed by the Bay Area Pollution Control District in San Francisco. This process weight regulation was based on well-controlled process industries found there. The Bay Area Curve rises to an allowable emission of 40 pounds per hour with increasing size of operation, and then allowable emissions increase at a reduced rate above 40 pounds per hour with increasing size of operation. The Bay Area Curve as applied to the State of Illinois regulation can be seen in Figure A.1. The Bay Area regulation is quite stringent for sources with a combination of large process weight rate and large emission factors, such as the SIC class 32 (stone, clay, and glass industries). It is noticeably lenient for sources with small emission factors and large process weight, such as SIC 28 (chemicals and allied) and SIC 29 (petroleum).

A.2 POINT-SOURCE PARTICULATE CONTROL DEVICES

When control regulations are enforced on a specific manufacturing plant, the source operator must select control equipment to meet the required reductions. It has been assumed in this study that the source operator will select that device which meets the design requirements of his plant configuration at least cost. In this section, the literature on control equipment is reviewed to determine which devices are applicable

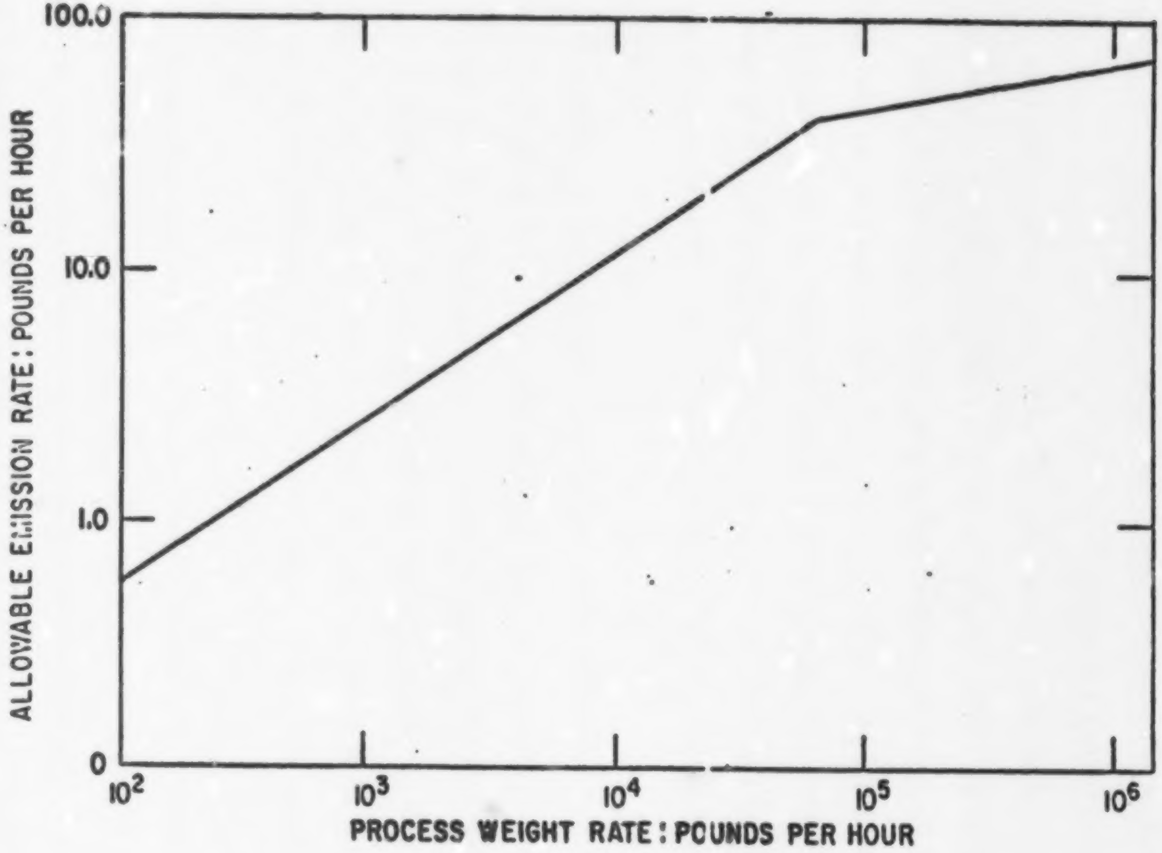

Figure A.1. State of Illinois allowable emission rate for point-source control

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Source: Op cit

to manufacturing processes, and to estimate the resulting costs. This information is needed to construct the control equipment cost model described in Appendix B.

A.2.1 Considerations in Control Device Selection for Manufacturing Processes

Control equipment for particulate air pollutants may be classified into several general types: scrubbers, gravitational collectors, cyclones, electrostatic precipitators, afterburners, and fabric filters. Control equipment for each process is designed on the basis of the physical behavior of the airborne particles emitted. Such physical behavior is governed by particle size and size distribution (ranging from hundreds of microns down to fractions of microns), specific gravity, shape, and chemical and surface properties.

In relation to particle characteristics and control device types, the American Industrial Hygiene Air Pollution Manual and the National Air Pollution Control Administration, now the U.S. Environmental Protection Agency, have reviewed process factors affecting equipment selection.[2,6] They analyze each of the control devices in detail as to principles of operation, construction, efficiency, power consumption, reliability, cost, and application.

Wet collectors or scrubbers are devices in which the prime means of collection is a liquid introduced into the collector for contact with the aerosol.[2,7,8,9,10] The overall particle size range that lends itself to wet collection is from 0.2μ to greater than 10μ. Wet collectors vary in design, but utilize methods to condition the particulate and disengage it from the carrier gas. The mechanisms designed for achieving this are impingement, Brownian motion, condensation of liquid on particles that serve as nuclei, and agglomeration of particles. Wet collection equipment is usually selected because of low first cost at reasonable efficiency, or because water may offer a more convenient method of disposal of the collected material. It is used readily where the particulates may cause a fire or explosion if not promptly wetted. In the selection of a wet collector, cost comparisons must include initial unit price and installation cost, as well as power, water, labor, and maintenance costs. Prices vary for the type of collector, but range from $0.50/cfm to $3.00/cfm at a capacity of 1,000 cfm.[2]

Inertial collectors include devices that collect particulate matter by gravity or centrifugal force.[2,11,12] Gravity collectors are devices that include settling chambers, baffled chambers, or louvered chambers, and operate on the principle that gravity or particle inertia increases with the square of particle diameter. Thus, the largest particles are separated most easily. As a result, collectors of this class are of relatively low efficiency and are frequently used as pre-cleaners preceding other types of collectors. Centrifugal collectors or cyclones are devices in which a vortex is created within the collector. This vortex propels particles to a location from which they may be removed. They may be operated wet or dry, and may either deposit the collected particulate matter in a hopper or concentrate it into a stream of carrier gas that flows to another separator. Most cyclones operate in the range from 50- to 90-percent efficiency, depending on the size of the particulate matter handled and the cyclone body diameter. Cyclones cost from $0.07/cfm to $0.50/cfm uninstalled, and have annual operating costs of $0.08 to $0.20/cfm, with ten-year amortization.[2]

Electrical precipitators are devices in which high intensity electrical fields cause particles to acquire an electrical charge and migrate to a collecting surface.[2,13,14,15,16] Pressure drop is very low, and collection efficiency increases with length of passage through the precipitator. Maintaining the design efficiency in daily operation is more difficult with precipitators than with many other devices. Precipitator efficiency is easily maintained at 75- to 90-percent, but above 98 percent sectionalization and automatic power controls must be employed.

Filters are porous structures for removal of particulate matter from gas streams.[2,17,18] The porous structure is most commonly a fabric, but can include beds of a large variety of substances such as metal turnings, coke, slag, wool, and sand. Filters generally improve in retention efficiency as the interstices in the porous structure begin to be filled by collected particles. This increase in efficiency is accompanied by an increase in pressure drop through the filter. To prevent decrease in gas flow, the filter must be cleaned or replaced periodically. The three most important costs associated with fabric filtration are the purchase cost, the cost of power, and the maintenance cost. Purchase costs for fabric filters generally run at $2.50 per square foot.

Afterburners employ the application of flame combustion to the disposal of gaseous pollutants, aerosols, and waste liquids.[2,19,20,21] The incineration of contaminated matter is justified on several counts:

1) Odor control.
2) Reduction in opacity of plumes.
3) Reduction in emissions of reactive hydrocarbons.
4) Reduction in explosion hazard.

In selecting from the above-named devices, control equipment that meets the technical requirements of the process and the desired emission reduction, the cost-effectiveness of pollutant reduction must be considered. The consulting firm of Ernst and Ernst, working under the auspices of the National Air Pollution Control Association, has developed a rapid method for estimating the cost of air pollution control equipment.[6,22] A general method is presented for rapidly estimating the total annual cost of four generic types of mechanical devices commonly used in controlling sources of particulate pollutants. The four types of devices are inertial collectors, wet scrubbers, electrostatic precipitators, and fabric filters. Estimates of the purchase and installation costs associated with the various sizes and efficiences of the four device types are also provided. In the case of installation costs (expressed as a percentage of purchase cost), mean values are also estimated to reflect the most typical installation experience that could be inferred from the various data sources available for each type of control device. These mean values permit the use of formulae to construct gross estimates of the high and low variations around the estimated total annual cost (capitalized purchase and installation cost, plus annual maintenance and operating cost) of a specified device. The value of the general method presented is that it provides a rapid means of constructing order-of-magnitude cost bounds within which the total annual cost of a particulate control device can reasonably be expected to fall, given only the major characteristics of an emission source and the cost of power and water in the source's locality.

In a test of the model, the cost of achieving various air quality levels in the Kansas City study area, under different abatement strategies, is estimated.[23] The pollutants of interest in this study are suspended particulates and sulfur oxides. Emissions come from combustion of fossil fuels for space heating and power generation, from open burning and incineration of solid and liquid waste, from industrial processes, and from miscellaneous small sources. Stationary sources account for over 86 percent of the particulates and over 96 percent of the sulfur oxides emitted in this area.

The New York metropolitan area was also studied in a cost-effectiveness study of particulate and sulfur oxide emission control.[24] The annual cost of alternative methods for reducing particulate and sulfur oxide emission from power plants, stationary combustion sources, and incinerators is estimated. The alternatives include changing types of fuel and installing various pieces of control equipment.

A similar study to formulate the cost of emission control was prepared by the TRW Systems Group in Washington, D. C. They prepared an operator's manual for the Air Quality Implementation Program.[25] The Implementation Planning Program is a collection of computer programs designed to assist state governments in preparing their implementation plans for sulfur oxides and particulates. The regional air quality implementation process was based on the application of a set of stationary source emission controls in the form of emission standards. The many combinations of these standards result in a variety of possible control strategies. Through application of computer simulation techniques, the Implementation Planning Program was used in selecting appropriate emission standards, evaluating the resulting air quality, and determining the costs associated with various alternative control strategies. The individual programs, their input data requirements, and the output information generated were described in this volume. Sources such as fuel use, diffusion models, and various control equipment were mentioned.

A sensitivity analysis of selected Air Quality Implementation Planning Program input parameters was performed by the above-mentioned group.[26] A major problem in the analysis of regional air pollution abatement (control) strategies is the collection and verification of an adequate data base. If computer programs are used, the scope of the data base must be expanded to include effective stack parameters and regional cost data. As an aid in the definition and use of these parameters, their sensitivity, with respect to pollutant concentration value, and/or annual device costs were determined. The atmospheric diffusion model and the control cost model of the Air Quality Implementation Program were utilized. Sensitivity analyses were made for two sets of relevant parameters: (1) effective stack height parameters for individual sources; and (2) regional cost parameters with respect to the annual control cost of each physical device available in the IPP control cost model. Other parameters included stability wind rose, mixing height, ambient temperature and pressure, plume rise, exit velocity, and wind velocity. Control devices included scrubbers, centrifugal collectors, electrostatic precipitators, impactors, fabric filters, and afterburners; other control processes considered were flue gas desulfurization, catalytic oxidation, by-product manufacturing, and limestone injection.

Another user's manual developed by Anderson[27] suggests automated procedures for estimating control costs and emission reductions for specified air pollution sources. Other researchers can use and modify the computer programs developed within this manual for estimating emissions of specified industrial air pollution sources, and costs of controlling them. The output from each source program consists of emission estimates, both before and after control, as well as required control costs on a plant-by-plant basis. The manual describes the input requirements, operational characteristics, and output characteristics for each program. A master report-generating program was also developed. This program uses as input the output from one, all, or any combination of source programs; it generates summary data in the form of a single industry or multiple industries, and sums within the range of a desired geographical area. The area may be a single air quality control region or a state, or a combination of such. Computer programs are presented for petroleum refining, manufacture of phosphate fertilizer or sulfuric acid, kraft pulping, foundry operations, primary nonferrous metallurgy, steam electric plants, and other industries.

A similar program was developed by W. E. Jackson[28] at Drexel Institute of Technology. He describes a general procedure that can be followed for estimating the cost of reducing air pollution emissions within a given metropolitan region. The six-step procedure examines emission inventories, regional trends, control trends, alternate control schemes, control costs, and optimum cost-effectiveness. The procedure is illustrated for one emission source in the Delaware Valley.

The need for particulate control equipment has been well documented, but systematic methods of selecting the equipment are far from being established. Equipment for air pollution abatement was present at the Economics of Environmental Pollution Abatement, Creative Manufacturing Seminar.[29] The cost and effectiveness of air pollution control installations were closely related to efficiency capabilities, capacity, and control equipment selected. The factors that affect selection of equipment and important characteristics of control units were examined. The inertial or mechanical type of equipment considered were settling chambers, baffles, cyclone collectors, impingers, and dynamic collectors. A second category consisted of air washers, impingement scrubbers, submerged nozzles, dynamic scrubbers, spray towers, packed towers, and venturi scrubbers. Fabric filters and electrostatic precipitators were also described. Operational limitations, comparative efficiencies, and costs were considered.

In selecting equipment for air pollution abatement, Charles Stone[30] develops systematic techniques for selecting particulate control equipment. Utilizing adaptive identification procedures, he formulates an idealized mathematical model of the control system. By application of appropriate criteria functions, geometric programming, and parameter-estimation techniques, the parameters of a feasible particulate control system are synthesized in such a way that the difference between the idealized model response and the actual system response is minimized. This selection and automated parameter adjustment procedure yields a particulate air pollutant control system that is optimal with respect to the physical and economic constraints imposed upon the system. Cost-effectiveness relationships are also included.

In the selection of air pollution control equipment for particulate emissions, the types of devices fall into four general types: filters, electrostatic precipitators, dry inertial collectors, and wet scrubbers. In cases of complex emissions, these devices are combined. The basic operating principles of these devices involve certain basic data requirements. As an absolute minimum, the following data are required: gas volumetric flow rate, temperature, pressure, and humidity; particulate form and concentration; particulate size distribution and specific gravity; particulate bulk electrical resistivity (dry); required removal efficiency; and process constraints with regard to the use of water. From these basic data, it is possible to perform an initial screening on the type of system required. This screening defines technically feasible alternate solutions. Selection of the optimum equipment requires a detailed analysis of additional technical and economic factors, including capital investment, operating costs, and costs of capital. These operating principles, delineated by A.B. Walker,[31] were seen in all the literature concerning selection of particulate control equipment.

A.2.2 Variation of Control Devices by Industry

The nature of the particular industrial process dictates the type of control equipment used. For example, high gas temperature without cooling precludes the use of fabric filters, explosive gas streams prohibit the use of electrostatic precipitators, and submicron particles cannot generally be efficiently collected with mechanical collectors. The variation of control devices by industry can be seen in the following review of the literature.

Norman G. Edminsten studied the cost of air pollution and defined and quantified the cost variation for air pollutant emissions that exist from one industrial segment to another.[32] Several source studies were conducted. The areas include: gray iron foundries, steam electric power generation, asphalt batching, integrated iron and steel manufacturing, pulp and paper production, cement manufacturing, aluminum ore reduction, sulfuric acid manufacturing, and petroleum refining. Pollutant sources and the types and quantities of pollutants emitted are defined, as well as specific problems that must be considered in basic equipment design and operation. Estimated costs for control equipment range from $0.045/acfm for centrifugal collectors to $3.00/acfm for an electrostatic precipitator.

The cement industry has been studied by Robert E. Kohn, who developed a mathematical programming model for air pollution control at Washington University. Mathematical models are proposed in (33, 34) for computer processing to determine the least possible cost of pollution controls in an airshed. Advantages of the models are their simplicity, their emphasis on economic efficiency, and their appropriateness for the type of data normally available. One model considers a hypothetical airshed for a single industry: cement manufacturing. Annual production is 2,500,000 barrels of cement; two pounds of dust are emitted for every barrel produced. The least-cost solution to the emission problem would be to install a four-field electrostatic precipitator on kilns producing 1,000,000 barrels and a five-field precipitator on kilns producing 1,500,000 barrels. A second model concerns five major pollutants in the St. Louis airshed in 1970: sulfur dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, and particulates. Among the possible control methods included in the model are exhaust and crankcase devices for automobiles, the substitution of natural gas for coal, catalytic oxidation of sulfur dioxide to sulfuric acid at power plants, and the use of low-sulfur-content coal. Pollutant reduction requirements are itemized, the computer-derived solution of this model indicates the cost and efficiency of each reduction method. A third model indicates the effects of air pollution on humans, vegetation, and materials. It can be used to determine whether the relative damaging effects of pollutants are proportional to their control costs.

The Harvard Business Review published a paper[35] on industry action to combat pollution. The responsibilities of individual corporations in air pollution abatement are emphasized. Sources of pollution discussed include the paper, steel, electric power, transportation, and petroleum industries. Principal equipment for removal of aerosols and particulates is described. It is concluded that although air pollution equipment increases costs in certain industries, recovery of pollutants, such as fly ash, may help to offset costs. Government activities in air pollution programs are also summarized.

The American Institute of Plant Engineers conducted a survey of industrial air pollution control equipment on operation costs and procedures.[36] The following industries are included: food, chemicals, rubber and plastics, stone, clay and glass, primary metals, fabricated metals, powered machinery, electrical machinery, professional and scientific instruments, and aerospace manufacturing. Emphasis of the results centers on capital, installation, and operating costs for air pollution control equipment. Other topics considered include: effectiveness, maintenance, equipment, corrosion, necessary design improvements, uncontrolled pollutants, and unsolved problems.

The American Institute of Chemical Engineers presented a report[37] on particulate control technology in the primary non-ferrous smelting industry. The sources and nature of particulate emissions and control technology in the primary smelting of aluminum, copper, lead, and zinc are described. High dust concentrations generated by bauxite drying and alumina calcining frequently require multicyclones for preliminary collection, followed by electrostatic precipitators. Installed costs for the combined system are from $4.60 to $2.30/cfm at 99+percent collection efficiencies. Electrolytic aluminum reduction cells pose a more complicated emission problem: moderate-energy wet scrubbers, glass filter bags, or flushed precipitator installations are used. Representative installed costs for the three methods are $3.00/cfm, $2.00/cfm, and $2.00/cfm, respectively. Dry electrostatic precipitators, preceded by mechanical collectors, are universally applied in copper smelting. Installation costs for the combined equipment are $6.00/cfm for 50,000-cfm flows, and $3.00/cfm for 2,000,000-cfm flows. Large lead blast furnaces employ electrostatic precipitators; small units use fabric filters. Installation costs of vertical flow pipe type precipitators in the 100,000-cfm range are $6.00/cfm. Continuous bag-houses for smaller volumes cost $5.00/cfm installed. Horizontal flow plate precipitators are used on new zinc sintering machines. Mild steel construction is common, and installed costs for 50,000-cfm collectors are $3.50/cfm in the study. Emissions from flash roasting of zinc ore are also controlled by plate-type precipitators of mild steel construction. Installed costs are $3.50/cfm.

Iron and steel industry emissions have been examined with respect to specific sources, control methods, and annual costs.[38,39] The majority of operations report using fabric filters or wet collectors to control particulate pollution.

The pulp and paper industry employs control equipment to satisfy air pollution control regulations, and J. D. Rushton[40] and J. E. Robertson[41] each contributed literature on factors to consider in selecting air pollution control equipment. The foundry industry likewise has surveyed the entire subject of air pollution in foundry production, and some solutions to the major problems are presented.[42,43,44] Feed and grain mills and alfalfa dehydrating mills have been analyzed by the Public Health Service to determine air pollution control needs in meeting air standards.[45,46] Air pollution aspects of the brass and bronze smelting and refining industry was another aspect of the Public Health Service analysis, as was the hot mix asphalt paving batch plants. Both of these reports focus on pertinent information about the raw materials used, basic equipment, plant operation, air pollution problems, and air pollution control equipment, with cost analysis.[47,48]

Methods and costs of air pollution control were reviewed, with emphasis on the efforts of the chemical process industry, by I. Schwartz.[49] The magnitude of the task is shown by Public Health Service estimates of the amount of pollutants poured into the atmosphere each year: particulates, 15 million tons; sulfur oxides, 30 million tons; hydrocarbons, 24 million tons; carbon monoxide, 87 million tons; nitrous oxides, 17 million tons. With the chemical processing industry, the percentage of capital outlay for air pollution control equipment is expected to change. Expenditures for particulate controls account for more than one-third of industry expenditures.

Gaseous emission controls, currently less than 2 percent of sales, are expected to jump to 40 percent following development of federal gaseous emission criteria. The Department of Health, Education, and Welfare guidelines for air quality criteria issued to date are listed in the report. The cost of compliance with their suggestions are estimated. For the sulfuric acid industry, this estimate is from $26 to $39 million capital expenditure and from $1.5 to $2.8 million per year operating cost. For the phosphate fertilizer industry, the estimates are from $3.1 to $6.7 million and from $1.3 to $2.7 million, respectively. The four basic means of collecting particulates (fabric filter, electrostatic precipitator, cyclone, and scrubber) are described, along with their capabilities and costs. The three basic systems for gaseous emission control (scrubbing, absorption, and incineration) are similarly treated. By-product recovery is evaluated as a means of reducing the effective cost of air pollution control.

A yearly expenditure, as Schwartz has computed for the chemical process industry, can also be computed for controlling major air pollutants. The federal government annually published the Economics of Clean Air, which is a report of the administrator of the Environmental Protection Agency to the Congress of the United States in compliance with the amendments to the Clean Air Act.[50] The March 1972 edition reports on the prospective costs and impacts of governmental and private efforts to carry out the provisions of Section 312 of the Clean Air Act.

Cost estimates for controlling major air pollutants from most stationary and mobile source types, computed for the first time on a national level, are given in this report. For mobile sources, three pollutants are covered: carbon monoxide, hydrocarbons, and nitrogen oxides. For stationary sources, five pollutants are covered: particulates, sulfur oxides, carbon monoxide, hydrocarbons, and nitrogen oxides. Three general classes of stationary sources are considered: solid waste disposal (open buring and incineration), stationary fuel combustion (heating and power generation), and industrial processes (seventeen types). Stationary source control costs are projected for the five fiscal years 1973 through 1977. Mobile source control costs are given for the 1968-1977 model to show the relative impact of increasingly more stringent federal standards since 1967.

A.2.3 Summary of Control Literature

Gas streams contaminated with particulate matter may be cleaned before the gas is discharged to the atmosphere. Gas cleaning devices take advantage of certain physical, chemical and/or electrical properties of the particulate matter and gas stream. Selection of a gas cleaning device will be influenced by the efficiency required; nature of the process gas to be cleaned; characteristics of the particulate and gas stream; cost of the device's use; availability of space; and power and water requirements. Other basic considerations include maintenance, dependability and waste disposal. Table A.2 shows a list of the types and values of control equipment being sold to various industries by end use in 1967. As a further aid in the selection of particulate matter collection equipment, the areas of application of the various cleaning devices are given in Table A.3.[6] The selection of applicable control devices as shown in the literature was utilized in the cost-effectiveness model,as seen in Appendix B.

Table A.24—MANUFACTURERS' SHIPMENTS OF INDUSTRIAL GAS CLEANING EQUIPMENT BY END USE IN 1967 *

[Thousands of dollars]

	Electrostatic precipitators	Fabric filters	Mechanical collectors	Scrubbers particulate	Scrubbers gaseous	Gas incinerators and adsorbers	Total shipments
Iron and steel	5,783	4,536	2,300	7,423	4,275	(b)	24,317 [b]
Utilities	15,506	(a)	2,476	(a)	(a)	(a)	18,481
Chemicals	1,207	5,344	3,130	3,709	1,479	1,001	15,870
Rock products [c]	2,760	3,602	1,038	1,142	(a)	(a)	8,966
Pulp and paper	(a)	122	802	989	193	(a)	6,753
Mining and metallurgical	(a)	1,855	389	825	394	(a)	6,160
Refinery	(a)	(a)	(a)	(a)	(a)	282	4,098
All other [d]	687	4,959	8,408	3,901	114	2,137	20,206
Exports	(a)	1,081	(a)	651	72	79	5,744
Total shipments	36,509	21,730	22,381	19,229	6,770	3,976	110,595

[a] Not published to avoid disclosure.

[b] Gas incinerators and adsorbers purchased by iron and steel companies are included in "all others" category to avoid disclosure.

[c] "Rock products" includes cement and asbestos plants.

[d] "All other" includes shipments to distributors where end use cannot be identified.

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*Source: Control Techniques for Particulate Air Pollutants. National Air Pollution Control Administration Publication AP-51. January 1969.

Table A.3. USE OF PARTICULATE COLLECTORS BY INDUSTRY*

Industrial Classification	Process	EP	MC	FF	WS	Other
Utilities and Industrial power plants	Coal	0	0	-	-	-
	Oil	0	0	-	-	-
	Natural gas	-	-	-	-	-
	Lignite	0	0	-	-	-
	Wood and bark	+	0	-	+	-
	Bagasse	-	0	-	-	-
	Fluid coke	0	+	-	-	+
Pulp and paper	Kraft	0	-	-	0	-
	Soda	0	-	-	0	-
	Lime kiln	-	-	-	0	-
	Chemical	-	-	-	0	-
	Dissolver tank vents	-	0	-	-	+
Rock products	Cement	0	0	0	+	-
	Phosphate	0	0	0	0	-
	Gypsum	0	0	0	0	-
	Alumina	0	0	0	+	-
	Lime	0	0	+	-	-
	Bauxite	0	0	-	-	-
	Magnesium oxide	+	+	-	-	-
Steel	Blast furnace	0	-	-	0	+
	Open hearth	0	-	-	+	+
	Basic oxygen furnace	0	-	-	0	-
	Electric furnace	+	-	0	0	-
	Sintering	0	0	-	-	-
	Coke ovens	0	-	-	-	+
	Ore roasters	0	0	-	+	-
	Cupola	+	-	+	0	-
	Pyrites roaster	0	0	-	0	-
	Taconite	+	0	-	-	-
	Hot scarfing	0	-	-	+	-
Mining and metallurgical	Zinc roaster	0	0	-	-	-
	Zinc smelter	0	-	-	-	-
	Copper roaster	0	0	-	-	-
	Copper reverb	0	-	-	-	-
	Copper converter	0	-	-	-	-
	Lead furnace	-	-	0	0	-
	Aluminum	0	-	-	0	+
	Elemental phos	0	-	-	-	-
	Ilmenite	0	0	-	-	-
	Titanium dioxide	+	-	0	-	-
	Molybdenum	+	-	-	-	-
	Sulfuric acid	0	-	-	0	0
	Phosphoric acid	-	-	-	0	0
	Nitric acid	-	-	-	0	0
	Ore beneficiation	+	+	+	+	+
Miscellaneous	Refinery catalyst	0	0	-	-	-
	Coal drying	-	0	-	-	-
	Coal mill vents	-	+	0	-	-
	Municipal incinerators	+	0	-	0	+
	Carbon black	+	+	+	-	-
	Apartment incinerators	-	-	-	0	-
	Spray drying	-	0	0	+	-
	Machining operation	-	0	0	+	+
	Hot coating	-	-	-	0	0
	Precious metal	0	-	0	-	-
	Feed and flour milling	-	0	0	-	-
	Lumber mills	-	0	-	-	-
	Wood working	-	0	0	-	-

Key:

0=Most common
+=Not normally used
EP=Electrostatic Precipitator
MC=Mechanical Collector
FF=Fabric Filter
WS=Wet Scrubber

Other=Packed towers
Mist pads
Slag filter
Centrifugal exhausters
Flame incineration
Settling chamber

Source: Op cit.

A.3 LAND USE PLANNING AND AIR POLLUTION

Although the meteorology and topology of a metropolitan region enhance or inhibit pollution dispersion, it is the intensity and spatial distribution of human activity that largely determines air quality, for such activity accounts for most air pollutant emissions. Emission densities are also affected by the air pollution control devices that are applied to reduce the quantity of pollutants reaching the atmosphere. Such control measures may be the result of attempts to reduce the externalities imposed on the residents of a metropolitan region by pollution-producing activities, to retain pollutant emissions that can be economically recovered and recycled, or to achieve some combination of these two purposes.

There are two major studies that fall in the category of the relationship of land use planning and air pollution control. The development of methodologies for the integration of air resource management with urban and regional planning has been in progress at Argonne National Laboratory of the Atomic Energy Commission, under the auspices of the Environmental Protection Agency. The purpose of the study is to apply systems analysis methods to episode and long-range air pollution control planning.[1,3,51,52] The program includes:

1) Design and testing of a computerized model for the projection of urban and regional growth trends in energy demand, industrial and commercial activities, and residential development. The model generates such projections and translates them into a projected air pollution emission inventory that provides input to an atmospheric dispersion model. The result is a projection of future expected urban air quality.

Such projections have been developed for the Chicago region for the years 1975 and 1980.

2) Development and testing of a methodology for the acquisition and computer storage of a regional zoning inventory. This system provides a data base for a land-use-oriented atmospheric model that yields sulfur oxide and suspended particulate air pollution control strategies; these strategies exploit an emission density limitation on land use as the regulatory instrument for a land-use-based air control program. This system can be used to assess the air pollution impact of urban development.

3) Testing of atmospheric dispersion modeling techniques designed to operate on data that is usually collected by planning agencies. Adaptation of air pollution impact analysis methods to the capabilities of planning agencies to utilize these techniques.

4) Design and evaluation of air pollution control strategies based on locational devices such as zoning.

5) Integration of air pollution analysis techniques into comprehensive planning, analysis, and evaluation systems.

The researchers conclude that one of the most effective ways of integrating metropolitan air pollution control and land use planning is through the use of emission-density-limited zoning plans specifying the maximum emission rates per areal unit of land for different land use categories. A procedure was formulated to make this concept operational.

With the establishment of emission density limitations for each category of land use, relatively well-defined rights are added to the property rights associated with each parcel of land in the metropolitan area. Under the emission density approach to controlling air pollution, several options exist for complying with the regulations; two of these options are not available under current approaches to air pollution control. As with existing programs that regulate emissions on a source-by-source basis, a pollutant-producing activity may reduce the amount of pollution emitted by fuel, raw material, or process changes, or by installing mechanical control equipment. If none of these options is sufficient to achieve the necessary reduction in emissions, or if all of them are prohibitively costly, more land may be purchased for the pollutant-producing activity or, alternatively, the emission rights of adjacent property may be purchased.

The second study[53] directed toward air pollution control and urban planning is a joint effort of the Environmental Protection Agency and the New Jersey Department of Environmental Protection. The general objectives of the study were to develop methods for forecasting emissions and concentrations of five major pollutants (sulfur oxides, particulates, carbon monoxide, hydrocarbons, and nitrogen oxides) resulting from the implementation of alternative land use plans, and the formulation of procedures for evaluating the relative desirabilities of alternative plans once their air pollution potentials have been estimated. The forecasting methods and evaluation techniques were to be applied to alternative plans prepared by the New Jersey Department of Community Affairs for an 18,000-acre tract of now mostly vacant meadows, marshes, and salt-water swamps in northeastern New Jersey across the Hudson River from Manhattan Island, New York. A #300 million Army Corps of Engineers flood control project had been proposed to enable reclamation and development of the area.

The dispersion model was relied upon as the method being used in the New Jersey study for estimating air pollutant concentrations. A process was devised for translating land use data into the emissions input necessary for the dispersion model. Several different ways of evaluating and ranking alternative plans were being examined, including the relative degrees of plan compliance with air quality standards and the differing extents to which plans would result in the exposure of populations to undesirably high pollutant concentrations.

A.4 SUMMARY OF THE LITERATURE REVIEW

As can be seen from the review of the literature:

1) Control equipment may be classified into several general types.

2) Estimated costs range from \$0.045/acfm for centrifugal collectors to \$3.00/acfm for electrostatic precipitators.

3) Operating principles depend upon the size, distribution, specific gravity, shape, and chemical and surface properties of airborne particles.

4) Cost variation for air pollutant emissions exist from one industrial segment to another.

5) Land use planning affects the intensity and spatial distribution of air pollutant dispersions.

6) A great amount of research has been accumulated on the aspects of point source control in achieving air quality.

7) Very little work has been done in the new area of emission-density-limited zoning.

8) Virtually no work has been done on the economic implication of the relationship associated with the two strategies in achieving air quality.

This study attempts to determine the most economical means of achieving air quality, either by point-source control or emission-density-limited zoning.

APPENDIX B SOURCE-CONTROL COST-EFFECTIVENESS MODEL

The purpose of the source-control cost-effectiveness model is to select that control device for a given process that meets the technical requirements of the process, and achieves a specified efficiency in removing pollutants from the effluent stream, at the least annualized cost to the source owner. The set of commercially available particulate control devices is listed in Table B.1. Each process type required examination within its four-digit SIC group to determine which of the applicable devices could be feasibly installed on the process. The final list of control devices that actually could be applied to each process type, as reviewed from the literature, and their efficiencies are listed in Tables B.2-B.6.

The annualized cost of each control device that met the required reduction was computed from the purchase cost, installation cost, capital cost, and operation and maintenance cost for point-source control. The device that achieved the optimum condition of least cost was then computed from the following equation:

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Table. B.1. POLLUTION REDUCTION DEVICES OR METHODS

Code No.	Control Device
001	Wet scrubber - high efficiency
002	Wet scrubber - medium efficiency
003	Wet scrubber - low efficiency
004	Gravity collector - high efficiency
005	Gravity collector - medium efficiency
006	Gravity collector - low efficiency
007	Centrifugal collector - high efficiency
008	Centrifugal collector - medium efficiency
009	Centrifugal collector - low efficiency
010	Electrostatic precipitator - high efficiency
011	Electrostatic precipitator - medium efficiency
012	Electrostatic precipitator - low efficiency
013	Gas scrubber
014	Fabric filter - high temperature
015	Fabric filter - medium temperature
016	Fabric filter - low temperature
017	Catalytic afterburner
018	Catalytic afterburner with heat exchanger
019	Direct flame afterburner
020	Direct flame afterburner with heat exchanger
021	Cyclones in series
022	Cyclone + wet scrubber
023	Cyclone + packed scrubber
024	Cyclone + gas scrubber
025	Cyclone + fabric filter
026	Scrubber + electrostatic precipitator - medium efficiency
027	Cyclone + electrostatic precipitator
028	Electrostatic precipitator + cyclone + fabric filter
029	Scrubber + afterburner
030	Fabric filter + scrubber
031	Eliminate coal combustion
032	Eliminate coal and residual fuel oil combustion
033	Change all fuel use to natural gas

Source: Air Quality Implementation Planning Program Operators Manual, I.
TRW Systems Group. Washington, D.C.

Table B.2. EFFICIENCIES OF APPLICABLE CONTROL DEVICES FOR STATIONARY COMBUSTION SOURCES, PETROLEUM, AND WOOD PROCESSING

	Wet Scrubber High Efficiency	Wet Scrubber Medium Efficiency	Wet Scrubber Low Efficiency	Gravity Collector High Efficiency	Gravity Collector Medium Efficiency	Gravity Collector Low Efficiency	Centrifugal Collector High Efficiency	Centrifugal Collector Medium Efficiency	Centrifugal Collector Low Efficiency	Electrostatic Precip. High Efficiency	Electrostatic Precip. Medium Efficiency	Electrostatic Precip. Low Efficiency	Gas Scrubber	Fabric Filter High Temperature	Fabric Filter Medium Temperature	Fabric Filter Low Temperature
STATIONARY COMBUSTION SOURCES																
Bituminous Coal	99	80	60	50	40	30	90	80	70	99.5	99	99	0	99.5	0	0
Anthracite Coal	99	80	60	50	40	30	98	80	70	99.5	99	99	0	99.5	0	0
Fuel Oil Comb.	99	80	60	5	0	0	30	10	70	99.5	99	99	0	99.5	0	0
Natural Gas Comb.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liq. Petro. Gas.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PETROLEUM																
Petroleum Refinery	0	0	0	0	0	0	90	80	0	99	95	0	0	0	0	0
WOOD PROCESSING																
Wood Pulping	0	0	0	0	0	0	97	0	0	0	0	0	0	0	0	0
Pulp Board	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Reisenweber, Richard L. A Cost Effectiveness Comparison of Point Source Controls and Emission Density Zoning As Strategies for Achieving Regional Air Quality. (Dissertation.) May 1973.

Table B.2. (Contd.)

	Catalytic Afterburner	Catalytic Afterburner w̄ Heat Exchanger	Direct Flame Afterburner	Direct Flame Afterburner w̄ Heat Exchanger	Cyclones in Series	Cyclone + Wet Scrubber	Cyclone + Packed Scrubber	Cyclone + Gas Scrubber	Cyclone + Fabric Filter	Scrubber + E. P. (Med. Efficiency)	Cyclone + Elec. Precip.	Elec. Precip. + Cyclone + Fabric Filter	Scrubbers + Afterburners	Fabric Filter + Scrubber	Eliminate Coal Combustion	Eliminate Coal and Residual fuel oil com.	Change all Fuel Use to Natural Gas
STATIONARY COMBUSTION SOURCES																	
Bituminous Coal	0	0	0	0	90	0	0	0	0	0	0	0	0	0			
Anthracite Coal	0	0	0	0	90	0	0	0	0	0	0	0	0	0			
Fuel Oil Comb.	0	0	0	0	90	0	0	0	0	0	0	0	0	0			
Natural Gas Comb.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Liq. Petro. Gas.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PETROLEUM																	
Petroleum Refinery	0	0	90	0	0	0	0	0	0	0	0	0	0	0			
WOOD PROCESSING																	
Wood Pulping	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Pulp Board	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

Table B.3. EFFICIENCIES OF APPLICABLE CONTROL DEVICES FOR SOLID WASTE DISPOSAL, EVAPORATION LOSS SOURCES, AND THE FOOD AND AGRICULTURAL INDUSTRY

	Wet Scrubber High Efficiency	Wet Scrubber Medium Efficiency	Wet Scrubber Low Efficiency	Gravity Collector High Efficiency	Gravity Collector Medium Efficiency	Gravity Collector Low Efficiency	Centrifugal Collector High Efficiency	Centrifugal Collector Medium Efficiency	Centrifugal Collector Low Efficiency	Electrostatic Precip. High Efficiency	Electrostatic Precip. Medium Efficiency	Electrostatic Precip. Low Efficiency	Gas Scrubber	Fabric Filter High Temperature	Fabric Filter Medium Temperature	Fabric Filter Low Temperature
SOLID WASTE DISPOSAL																
Refuse Incineration	95	87	80	30	20	10	80	50	30	96	93	90	0	99	99	99
Auto Body Inc.	95	87	80	0	0	0	0	0	0	0	0	0	0	0	0	0
Conical Burners	90	80	70	0	0	0	0	0	0	0	0	0	0	0	0	0
Open Burning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EVAPORATION LOSS SOURCES																
Dry Cleaning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Coating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petroleum Storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gasoline Marketing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FOOD AND AGRICULTURAL INDUSTRY																
Alfalfa Dehydrating	0	0	0	0	0	0	90	80	70	0	0	0	0	95	95	95
Coffee Roasting	0	0	0	0	0	0	70	65	60	0	0	0	0	0	0	0
Cotton Ginning	0	0	0	0	0	0	90	50	70	0	0	0	0	0	0	0
Feed & Grain Mills	0	0	0	0	0	0	90	80	70	0	0	0	0	95	95	95
Fermentation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish Processing	0	0	0	0	0	0	90	80	70	0	0	0	0	99	99	99
Meat Smokehouses	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0
Nitrate Fertilizer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
a. Prilling Tower	95	90	80	0	0	0	0	0	0	0	0	0	0	0	0	0
b. Granulator Dryer	0	0	0	0	0	0	70	60	50	0	0	0	0	99	99	99
Phosphate Fert.	70	70	70	0	0	0	0	0	0	0	0	0	0	99	99	99
Starch Manuf.	0	0	0	0	0	0	90	80	70	0	0	0	99.7	99	99	99
Sugar Cane Prod.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B.3. (Contd.)

	Catalytic Afterburner	Catalytic Afterburner w Heat Exchanger	Direct Flame Afterburner	Direct Flame Afterburner w Heat Exchanger	Cyclones in Series	Cyclone + Wet Scrubber	Cyclone + Packed Scrubber	Cyclone + Gas Scrubber	Cyclone + Fabric Filter	Scrubber + E. P. (Med. Efficiency)	Cyclone + Elec. Precip.	Elec. Precip. + Cyclone + Fabric Filter	Scrubbers + Afterburners	Fabric Filter + Scrubber	Eliminate Coal Combustion	Eliminate Coal and Residual fuel oil com.	Change all Fuel Use to Natural Gas
SOLID WASTE DISPOSAL																	
Refuse Incineration	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Auto Body Inc.	0	0	25	0	0	0	0	0	0	0	0	0	0	0			
Conical Burners	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Open Burning	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
EVAPORATION LOSS SOURCES																	
Dry Cleaning	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Surface Coating	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Petroleum Storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Gasoline Marketing	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
FOOD AND AGRICULTURAL INDUSTRY																	
Alfalfa Dehydrating	0	0	0	0	0	0	0	0	99.9	0	0	0	0	0			
Coffee Roasting	99	99	99	99	0	92	0	0	0	0	0	0	0	0			
Cotton Ginning	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Feed & Grain Mills	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Fermentation	0	0	99	0	0	0	0	0	0	0	0	0	0	0			
Fish Processing	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Meat Smokehouses	0	0	70	0	0	0	0	0	0	0	0	0	0	0			
Nitrate Fertilizer	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
a. Prilling Tower	0	0	0	0	0	97	0	0	0	0	0	0	0	0			
b. Granulator Dryer	0	0	0	0	0	97	0	0	0	0	0	0	0	0			
Phosphate Fert.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Starch Manf.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Sugar Cane Prod.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

Table B.4. EFFICIENCIES OF APPLICABLE CONTROL DEVICES FOR THE CHEMICAL PROCESS INDUSTRY

	Wet Scrubber High Efficiency	Wet Scrubber Medium Efficiency	Wet Scrubber Low Efficiency	Gravity Collector High Efficiency	Gravity Collector Medium Efficiency	Gravity Collector Low Efficiency	Centrifugal Collector High Efficiency	Centrifugal Collector Medium Efficiency	Centrifugal Collector Low Efficiency	Electrostatic Precip. High Efficiency	Electrostatic Precip. Medium Efficiency	Electrostatic Precip. Low Efficiency	Gas Scrubber	Fabric Filter High Temperature	Fabric Filter Medium Temperature	Fabric Filter Low Temperature
CHEMICAL PROCESS INDUSTRY																
Adipic Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	95	85	75	0	0	0	0	0	0	0	0	0	98	99.5	99.5	99.5
Carbon Black																
a. Channel Process	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b. Thermal Black Process	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c. Furnace	0	0	0	0	0	0	90	85	80	0	0	0	0	99.5	99.5	99.5
Charcoal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlor-Alkali	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Explosives	0	0	0	0	0	0	0	0	0	0	0	0	95	0	0	0
Hydrochloric Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrofluoric Acid	95	85	75	0	0	0	0	0	0	0	0	0	95	0	0	0
Nitric Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paint & Varnish	0	90	80	0	0	0	0	0	0	0	0	0	0	0	0	0
Phosphoric Acid	0	0	0	0	0	0	0	0	0	99.5	95	80	47	99	99	99
Phtalic Anhydride	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plastics	95	90	80	0	0	0	0	0	0	0	0	0	90	99	99	99
Printing Ink	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soap & Detergent	0	0	0	0	0	0	0	85	0	0	0	0	0	0	0	0
Sodium Carbonate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfuric Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synthetic Fibers	95	85	75	0	0	0	0	0	0	0	0	0	95	0	0	0
Synthetic Rubber	0	0	0	0	0	0	0	0	0	0	0	0	0	99	99	99
Terethalic Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B.4. (Contd.)

	Catalytic Afterburner	Catalytic Afterburner w Heat Exchanger	Direct Flame Afterburner	Direct Flame After-burner w Heat Exchanger	Cyclones in Series	Cyclone + Wet Scrubber	Cyclone ± Packed Scrubber	Cyclone + Gas Scrubber	Cyclone + Fabric Filter	Scrubber + E. P. (Med. Efficiency)	Cyclone + Elec. Precip.	Elec. Precip. + Cyclone + Fabric Filter	Scrubbers + Afterburners	Fabric Filter + Scrubber	Eliminate Coal Combustion	Eliminate Coal and Residual fuel oil com.	Change all Fuel Use to Natural Gas
CHEMICAL PROCESS INDUSTRY																	
Adipic Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Carbon Black																	
a. Channel Process	0	0	0	0	0	0	0	0	0	0	0	99.9	0	0			
b. Thermal Black Process	0	0	0	0	0	0	0	0	99.0	0	0	0	0	0			
c. Furnace	0	0	0	0	0	97	0	0	0	0	0	0	0	0			
Charcoal	0	0	99	99	0	0	0	0	0	0	0	0	0	0			
Chlor-Alkali	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Explosives	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Hydrochloric Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Hydrofluoric Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Nitric Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Paint & Varnish	0	90	0	90	0	0	0	0	0	0	0	0	0	0			
Phosphoric Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Phtalic Anhydride	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Plastics	0	0	99	99	0	0	0	0	0	0	0	0	0	0			
Printing Ink	0	0	0	0	0	0	0	0	0	0	0	0	90	0			
Soap & Detergent	0	0	0	0	0	92	95	97	0	0	0	0	0	0			
Sodium Carbonate	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Sulfuric Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Synthetic Fibers	0	0	99	99	0	0	0	0	0	0	0	0	0	0			
Synthetic Rubber	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Terethalic Acid	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

Table B.5. EFFICIENCIES OF APPLICABLE CONTROL DEVICES FOR THE METALLURGICAL INDUSTRY

	Wet Scrubber High Efficiency	Wet Scrubber Medium Efficiency	Wet Scrubber Low Efficiency	Gravity Collector High Efficiency	Gravity Collector Medium Efficiency	Gravity Collector Low Efficiency	Centrifugal Collector High Efficiency	Centrifugal Collector Medium Efficiency	Centrifugal Collector Low Efficiency	Electrostatic Precip. High Efficiency	Electrostatic Precip. Medium Efficiency	Electrostatic Precip. Low Efficiency	Gas Scrubber	Fabric Filter High Temperature	Fabric Filter Medium Temperature	Fabric Filter Low Temperature
METALLURGICAL INDUSTRY																
A. Primary Metals																
Aluminum	0	0	0	0	0	0	0	0	0	99	95	80	0	99	99	99
Met. Coke Manuf.	95	0	0	0	0	0	90	80	70	99	95	80	0	99	99	99
Copper Smelt	95	85	0	0	0	0	0	0	0	99.7	0	0	0	0	0	0
Ferroalloy Prod.	95	0	0	0	0	0	90	80	70	0	0	0	95	0	99	99
Iron Mills																
a. Blast Furnace	0	0	0	60	50	40	60	50	40	90	85	80	90	0	0	0
b. Sintering																
1. Windbox	0	0	0	0	0	0	90	80	70	99.5	0	0	0	0	99.5	0
2. Discharge	0	0	0	0	0	0	93	83	73	99.5	0	0	0	0	99.5	0
Steel Mills																
a. Open Hearth Fac.	0	0	0	0	0	0	0	0	0	98	88	78	98	99	99	99
b. Basic O_2 Furn.	0	0	0	0	0	0	0	0	0	99	89	79	99	0	0	0
c. Electric Arc Furn.	0	0	0	0	0	0	0	0	0	97	92	82	0	99	89	79
Lead Smelt	0	0	0	0	0	0	90	80	70	98	90	85	90	99	99	99
Zinc Smelt	0	0	0	0	0	0	0	0	0	99	95	80	0	99	99	99
B. Secondary Metals																
Aluminum OPS	95	90	80	0	0	0	0	0	0	0	0	0	0	99.6	99.6	99.6
Brass & Bronze Ingots	0	0	0	0	0	0	0	0	0	0	0	0	0	99.6	99.6	99.6
Gray Iron Foundry	95	90	0	0	0	0	85	77	70	99	95	90	0	99.6	99.6	99.6
Lead Smelting	95	90	80	0	0	0	0	0	0	0	0	0	0	99.6	99.6	99.6
Magnesium Smelting	95	90	80	0	0	0	0	0	0	0		0	0	99.6	99.6	99.6
Steel Foundries																
a. Electric Arc Furn.	0	0	0	0	0	0	0	0	0	98	95	85	99	0	0	0
b. Open Hearth	0	0	0	0	0	0	0	0	0	98.5	95	85	99	99.9	99.9	99.9
c. Open Hearth O_2 Lanced	0	0	0	0	0	0	0	0	0	98	95	85	98	99	99	99
Zinc Processing	95	90	80	0	0	0	0	0	0	0	0	0	0	99.6	99.6	99.6

Table B.5. (Contd.)

	Catalytic Afterburner	Catalytic Afterburner w Heat Exchanger	Direct Flame Afterburner	Direct Flame Afterburner w Heat Exchanger	Cyclones in Series	Cyclone + Wet Scrubber	Cyclone + Packed Scrubber	Cyclone + Gas Scrubber	Cyclone + Fabric Filter	Scrubber + E. P. (Med. Efficiency)	Cyclone + Elec. Precip.	Elec. Precip. + Cyclone + Fabric Filter	Scrubbers + Afterburners	Fabric Filter + Scrubber	Eliminate Coal Combustion	Eliminate Coal and Residual fuel oil com.	Change all Fuel Use to Natural Gas
METALLURGICAL INDUSTRY																	
A. Primary Metals																	
Aluminum	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Met. Coke Manuf.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Copper Smelt	0	0	0	0	0	0	0	0	99.9	0	0	0	0	0			
Ferroalloy Prod.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Iron Mills																	
a. Blast Furnace	0	0	0	0	0	90	0	0	0	0	0	0	0	0			
b. Sintering																	
1. Windbox	0	0	0	0	0	0	0	0	0	0	95	0	0	0			
2. Discharge	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Steel Mills																	
a. Open Hearth Fac.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
b. Basic O_2 Furn.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
c. Electric Arc Furn.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Lead Smelt	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Zinc Smelt	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
B. Secondary Metals																	
Aluminum CPS	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Brass & Bronze Ingots	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Gray Iron Foundry	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Lead Smelting	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Magnesium Smelting	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Steel Foundries																	
a. Electric Arc Furn.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
b. Open Hearth	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
c. Open Hearth O_2 Lanced	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Zinc Processing	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

Table B.6. EFFICIENCIES OF APPLICABLE CONTROL DEVICES FOR THE MINERAL PROCESS INDUSTRY

	Wet Scrubber High Efficiency	Wet Scrubber Medium Efficiency	Wet Scrubber Low Efficiency	Gravity Collector High Efficiency	Gravity Collector Medium Efficiency	Gravity Collector Low Efficiency	Centrifugal Collector High Efficiency	Centrifugal Collector Medium Efficiency	Centrifugal Collector Low Efficiency	Electrostatic Precip. High Efficiency	Electrostatic Precip. Medium Efficiency	Electrostatic Precip. Low Efficiency	Gas Scrubber	Fabric Filter High Temperature	Fabric Filter Medium Temperature	Fabric Filter Low Temperature
MINERAL PROCESS INDUSTRY																
Asphalt Batching	99.3	95	85	0	0	0	90	85	50	0	0	0	0	0	0	0
Asphalt Roofing	95	90	80	0	0	0	0	0	0	95	90	60	0	99	99	99
Bricks & Clay Prod.	95	90	80	0	0	0	90	85	50	0	0	0	0	99	99	99
Calcium Carbide Manuf.	95	90	80	0	0	0	0	0	0	0	0	0	95	99	99	99
Castable Refractories																
a. Raw Material Dryer	0	0	0	0	0	0	0	0	0	0	0	0	0	99	99	99
b. Raw Material Crushing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c. Elec. Arc Melt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d. Molding & Shakout	0	0	0	0	0	0	0	0	0	0	0	0	0	99	99	99
Port Cement Manuf.	0	0	0	0	0	0	80	70	60	99	95	90	0	99.5	99.5	99.5
Ceramic Clay Manuf.	95	90	80	60	50	40	75	70	65	99	95	90	0	99	99	99
Clay & Fly Ash Sint.	0	0	0	0	0	0	0	0	0	0	0	0	0	99	99	99
Coal Clean Dryers	0	0	0	0	0	0	70	60	50	0	0	0	0	0	0	0
Concrete Batching	95	90	80	0	0	0	90	85	80	0	0	0	0	99	99	99
Fiberglass Manuf.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frit Manuf.	0	0	0	0	0	0	0	0	0	0	0	0	67	99	99	99
Glass Manuf.	95	90	80	0	0	0	75	70	65	0	0	0	0	99	99	99
Gypsum Manuf.	95	90	80	0	0	0	90	85	80	99	0	0	0	99.5	99.5	99.5
Lime Manuf.	99.7	85	80	0	0	0	80	75	70	0	0	95	0	99.6	99.6	99.6
Mineral Wool Manuf.	60	50	40	0	0	0	0	0	0	0	0	0	0	0	0	0
Perlite Manuf.	0	0	0	0	0	80	70	60	0	0	0	0	0	96	96	96
Phosphate Rock Prep.																
a. Drying																
b. Grinding																
Stone Quarrying	0	0	0	0	0	85	80	70	0	0	0	0	0	99	99	99

Source: Op cit.

Table B.6. (Contd.)

	Catalytic Afterburner	Catalytic Afterburner w Heat Exchanger	Direct Flame Afterburner	Direct Flame After-burner w Heat Exchanger	Cyclones in Series	Cyclone + Wet Scrubber	Cyclone + Packed Scrubber	Cyclone + Gas Scrubber	Cyclone + Fabric Filter	Scrubber + E. P. (Med. Efficiency)	Cyclone + Elec. Precip.	Elec. Precip. + Cyclone + Fabric Filter	Scrubbers + Afterburners	Fabric Filter + Scrubber	Eliminate Coal Combustion	Eliminate Coal and Residual fuel oil com.	Change all Fuel Use to Natural Gas
MINERAL PROCESS INDUSTRY																	
Asphalt Batching	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Asphalt Roofing	0	0	0	0	0	0	0	0	99.9	85	0	0	0	0			
Bricks & Clay Prod.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Calcium Carbide Manuf.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Castable Refractories																	
a. Raw Material Dryer	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
b. Raw Material Crushing	0	0	0	0	0	70	0	0	0	0	0	0	0	0			
c. Elec. Arc Melt	0	0	0	0	0	0	0	0	0	0	0	0	0	98.4			
d. Molding & Shakout	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Port Cement Manuf.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Ceramic Clay Manuf.	0	0	0	0	0	90	0	0	0	0	0	0	0	0			
Clay & Fly Ash Sint.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Coal Clean Dryers	0	0	0	0	85	99.9	0	0	0	0	0	0	0	0			
Concrete Batching	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Fiberglass Manuf.	0	50	0	0	0	0	0	0	0	0	0	0	0	0			
Frit Manuf.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Glass Manuf.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Gypsum Manuf.	0	0	0	0	0	0	0	0	0	0	99	0	0	0			
Lime Manuf.	0	0	0	0	85	0	0	0	0	0	0	0	0	0			
Mineral Wool Manuf.	0	0	50	0	0	0	0	0	0	0	0	0	0	0			
Perlite Manuf.	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Phosphate Rock Prep.																	
a. Drying						99								0			
b. Grinding									99.9					0			
Stone Quarrying	0	0	0	0	0	99	0	0	99.9	0	0	0	0	0			

$$C^{*} = \min_{i \epsilon F(SIC)} C_i\ (x)$$

C^{*} = least cost

i = control device type index

C_i = cost of control device i

x = required reduction

F(SIC) = feasible set of applicable control devices for the specified four-digit SIC code.

Figure B.1 shows the relationship of the optimum cost and the required reduction as established by the optimum cost function.

B.1 COST MODEL FOR PARTICULATES

The total annual cost resulting from the assignment of a control device to a source involves the component costs of purchase cost, installation cost, capital cost, and operation and maintenance cost.

B.1.1 Purchase Cost

The purchase cost of control devices depends upon the characteristics and complexity of the control device and the size of the pollution source to be controlled. These parameters determine the basic cost equation for each control device in the form:

$$y = a + bx$$

where y = purchase cost in thousands of dollars

a and b = input coefficients

x = 10^3 acfm .

Table B.7 lists the manufacturer's price for the purchase cost equation by control device.

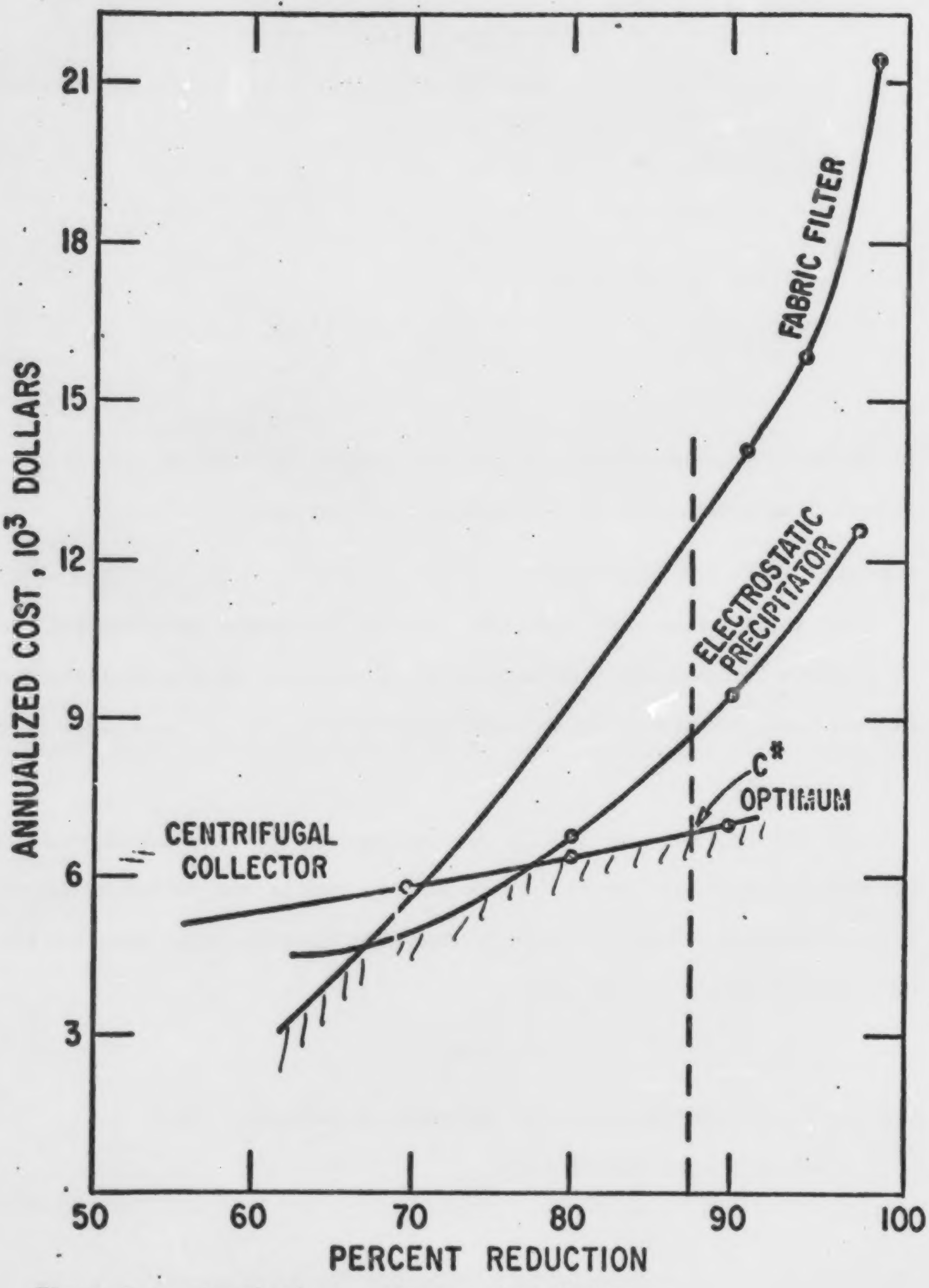

Figure B.1. Hypothetical optimum control device as established by the least-cost function

Table B.7. MANUFACTURER'S PURCHASE PRICE FOR CONTROL EQUIPMENT

Control Measure		Purchase Cost Equation
	WET COLLECTORS	
001	High efficiency	y = 2.886 + .228x*
002	Medium efficiency	
003	Low efficiency	y = 1.257 + .145x
	MECHANICAL COLLECTORS	
Gravity Collectors:		
004	High efficiency	y = .445 + .326x
005	Medium efficiency	y = .042 + .155x
006	Low efficiency	y = .003 + .056x
Centrifugal Collectors:		
007	High efficiency	y = 2.413 + .197x
008	Medium efficiency	y = 1.507 + .157x
009	Low efficiency	y = .244 + .099x
	ELECTROSTATIC PRECIPITATORS	
010	High efficiency	y = 42.413 + .623x
011	Medium efficiency	y = 31.243 + .441x
012	Low efficiency	y = 19.695 + .318x
	FABRIC FILTERS	
014	High temperature type	y = 1.448 + .838x
015	Medium temperature type	y = 3.478 + .448x
016	Low temperature type	y = 2.658 + .325x
	GAS SCRUBBER	
013		y = 3 175 + .251x
	INCREASED COMBUSTION EFFICIENCY (AFTERBURNER)	
017	Catalytic combustion	y = 7.550 + 1.515x*
018	Catalytic with heat exchange (1)	y = 7.550 + 1.515x
019	Direct flame combustion	y = 5.713 + 1.174x
020	Direct flame with heat exch. (1)	y = 5.713 + 1.174x

*Cost functions $y = 10^3$ dollars, $x = 10^3$ acfm.

B.1.2 Installation Cost

The installation costs of a control device on a particular plant are expressed as percentages of the purchase cost. These costs included the following items: erection, insulation material, transportation of equipment, site preparations, clarifiers and liquid treatment systems, and auxiliary equipment such as fans, ductwork, motors, and control instrumentation. These costs expressed as a percentage of purchase cost are shown in Table B.8

B.1.3 Capital Cost

Capital charges include overhead expenses such as taxes, insurance, and interest incurred in the operation of a control device. Annualized capital costs have been estimated in this study by depreciating the capital investment (the total installed cost or purchase installation) over the expected life of the control equipment and adding the capital charges of taxes and insurance. The assumptions made in capital cost are the following:

1) Purchase and installation costs are depreciated over fifteen years, a period assumed to be a feasible economic life for control devices.

2) The straight-line method of depreciation at six and two-thirds percent per year is used because it has the simplicity of constant annual writeoff.

3) Other capital charges, including interest, taxes, and insurance, are rated at twelve percent of the initial capital cost of the control equipment installed. Therefore, depreciation plus the annual charges amount to eighteen and two-thirds percent of the initial capital cost of the equipment.

Table B.8. INSTALLATION COST EXPRESSED AS A PERCENTAGE OF PURCHASE COST FOR CONTROL EQUIPMENT

Control Device	Code No.	Installation Cost Percent
Wet scrubber	001	200
	002	100
	003	100
Gravitational	004	67
	005	67
	006	67
Cyclones	007	50
	008	50
	009	50
Electronic precipitator	010	70
	011	70
	012	70
Gas scrubber	013	200
Fabric filter	014	75
	015	75
	016	75
Afterburner	017	25
	018	25
	019	25
	020	25
Series of cyclones	021	50
Cyclones + scrubbers	022	200
	023	200
	024	200
Cyclone + fabric filter	025	75
Scrubber + electrostatic precipitator	026	200
Cyclone + electrostatic precipitator	027	75
Electrostatic precipitator + cyclone + fabric filter	028	75
Scrubber + afterburner	029	200
Scrubber + fabric filter	030	200

Source: Control Techniques for Particulate Air Pollutants.
National Air Pollution Control Administration
Publication AP-51. January 1969.

The capital cost is calculated by the following relation:

$$\text{Capital cost} = \frac{i\,(1 + i)^N}{(1 + i)^N - 1} \quad ,$$

where i = 18-2/3 percent

N = 15 years.

The annual capital charge is then computed to be the product of the capital cost and the installed cost (purchase plus installation cost).

B.1.4 Operational and Maintenance Costs

The operational and maintenance costs have been computed from cost equations for the various control device types. The annual operating costs depend on the following factors: the gas volume cleaned, the pressure drop across the system, the operating time, the consumption and cost of electricity, the mechanical efficiency of the fan, and the scrubbing liquor consumption and costs.

The maintenance cost is the expenditure required to sustain the operation of a control device at its designed efficiency with a scheduled maintenance program and necessary replacement of any defective parts. On an annual basis, the maintenance cost is assumed proportional to the capacity of the device in acfm.

The cost equations used for the operation and maintenance of the devices are as follows:

1. Wet scrubbers

$$\text{OAMCOST} = S \left[0.7457 \;\; HK \left(Z = \frac{0h}{3960F} \right) + WHL + M \right]$$

2. Gravitational collectors, cyclones, and fabric filters

$$\text{OAMCOST} = S \left[\frac{0.7457}{6356E} \, PHK + M \right]$$

3. Electrostatic precipitators

$$OAMCOST = S \quad (JHK + M)$$

4. Afterburners

$$OAMCOST = S \quad \frac{0.7457}{6356E} \; PHK + HF + M$$

where S = design capacity in acfm

0.7457 = a constant (1 horsepower = 0.7457 kilowatts)

H = annual operating time (assumed 8,760 hours)

K = power costs, dollars per kilowatt hour

P = pressure drop across fan, inches of water

E = fan efficiency, assumed to be 60 percent

Z = contact power, horsepower per acfm

Q = liquor circulation, gallons per acfm

h = physical height liquor is pumped in circulation system, feet

F = pump efficiency, assumed to be 50 percent

W = make up liquor consumption, gallons per acfm

L = liquor cost, dollars per gallon

J = power requirements, kilowatts per acfm

F = fuel cost, dollars per acfm per hour

M = maintenance cost, dollars per acfm

The values utilized in the study constituted transportation costs and layout, and installation of control devices for the Chicago region.

Sources: Op cit.

Construction and Building Cost Indexes in 22 Cities. In: Engineering New Record, March, 1972.

B.2 APPLICATION OF SOURCE-CONTROL COST MODEL

The cost model described in the previous section has been computerized in subroutine form for easy linkage to other components of the system model. The subroutine is parameterized in terms of type of process, exhaust gas flow rate (action), and required emission reduction efficiency. This section provides an example of the results obtained from the application of the cost model to a typical point source.

Consider, a gray iron foundry in SIC class 3312 that has the following characteristics:

60,000 acfm

50,000 lb/hr process weight

350 lb/hr actual emissions (17.5 lb/ton emission factor
x 20 ton/hr process) .

From the Bar Area Curve, Table A.1., we see that at 50,000 lb/hr process weight there is an allowable emission of 35 lb/hr. Therefore, the percent reduction required is:

$$\left(1 - \frac{\text{allowable emission}}{\text{actual emission}}\right) \times 100 \text{ percent}$$

$$\left(1 - \frac{35}{350}\right) \times 100 \text{ percent} = 90 \text{ percent} \quad .$$

From Table B.5, it can be seen that high and medium efficiency scrubbers, centrifugal collectors, electrostatic precipitators, and fabric filters are applicable control devices to the gray iron foundry. The centrifugal collectors do not achieve the required efficiency, and their costs is not calculated. From Figure B.2, the purchase and installation cost of the control devices can be seen. Of the devices that apply, the wet scrubbers have the lowest purchase and installation costs, $41,040 for high efficiency and $27,360 for medium efficiency; while the electrostatic precipitators

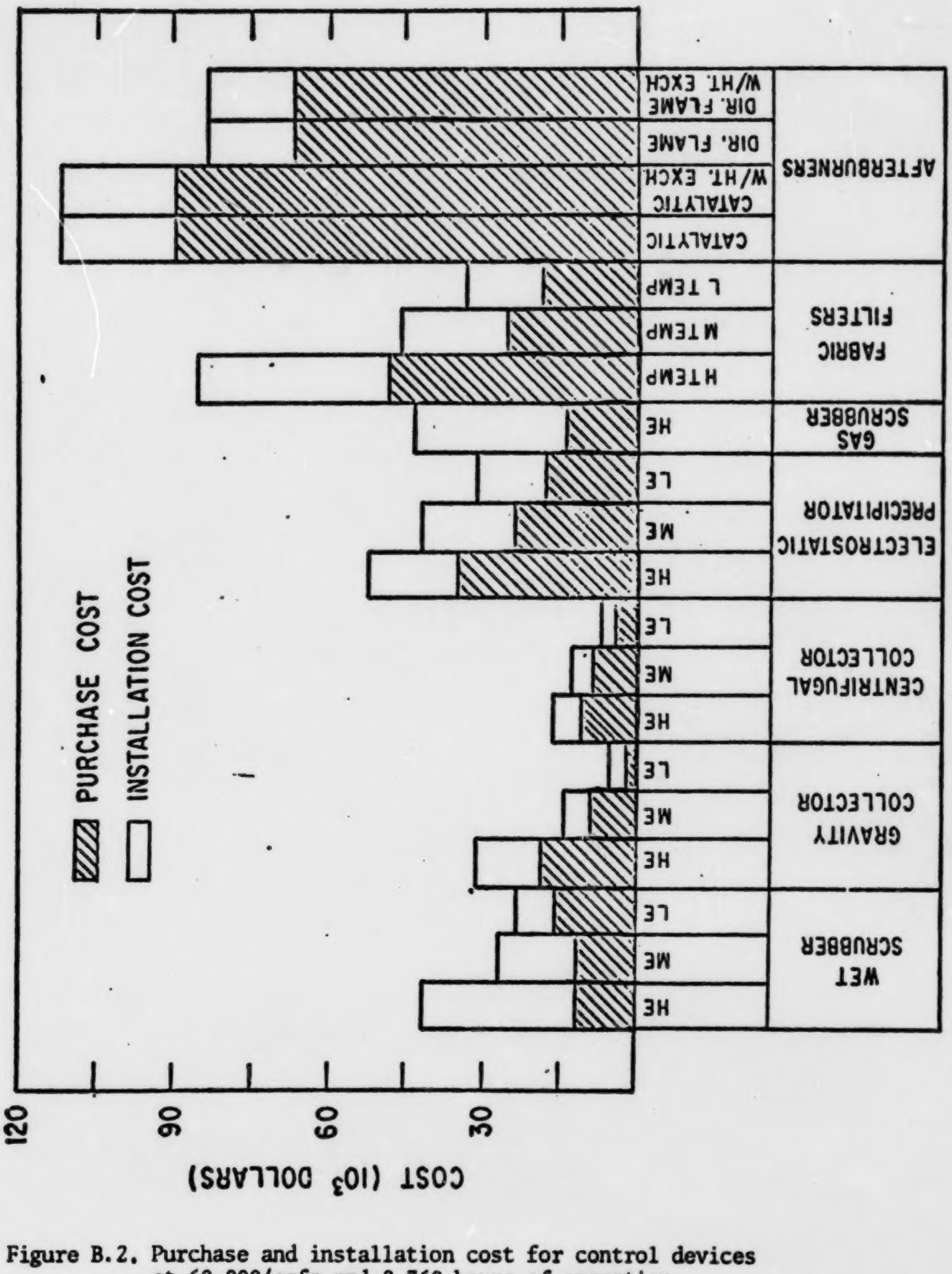

Figure B.2. Purchase and installation cost for control devices at 60,000/acfm and 8,760 hours of operation

are $54,550, $44,980, and $17,400 for high, medium, and low efficiency, respectively. The fabric filter costs depend on the exhaust temperature and range in cost from $87,590, $47,040, and $34,125 for high temperature, medium temperature, and low temperature fabrics, respectively. The capital costs have been calculated by depreciating the capital investment over the expected life of the control equipment and adding the capital charges of taxes and insurance.

Operation and maintenance charges have been calculated for the various types of control devices. Figure B.3 depicts the capital and operation and maintenance charges for mechanical collectors, electrostatic precipitators, and fabric filters. Figure B.4 depicts the charges for scrubbers and afterburners. As can be seen from the figures, the operation and maintenance charges are the primary costs with dry centrifugal collectors, scrubbers, and afterburners. The capital charge is the primary cost in selecting gravity collectors, electrostatic precipitators, and fabric filters. For the gray iron foundry, Tables B.9 and B.10 show that of the devices that apply and meet the required particulate emission reduction, the wet scrubbers have the greatest annualized cost, the fabric filters are intermediate in cost, and the electrostatic precipitators are the least costly. Therefore, the model selects the low-efficiency electrostatic precipitator as the control device to meet the 90-percent required reduction. The total annualized cost for the gray iron foundry selected as an example is $9,726. Of this charge, $6,560 is attributed to capital charges, and $3,166 to operation and maintenance charges. Of the operation and maintenance charge, $1,498 constitutes electrical costs, and $1,668 constitutes maintenance costs. The delineated costs of other control devices not applicable to the example cited can be seen in Tables B.11 and B.12.

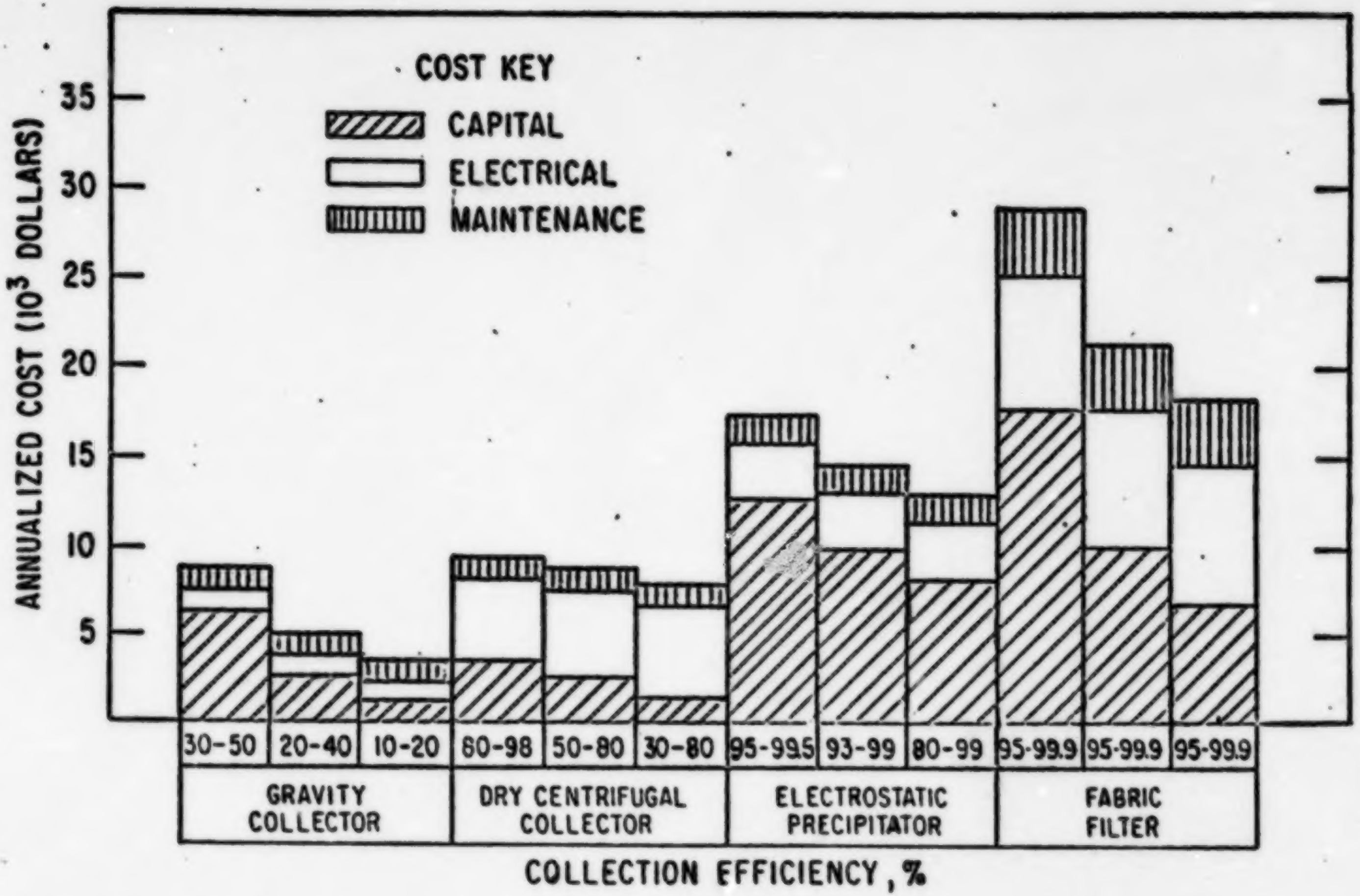

Figure B.3. Annualized costs for mechanical collectors, electrostatic precipitators, and fabric filters at 60,000/acfm and 8,760 hours of operation

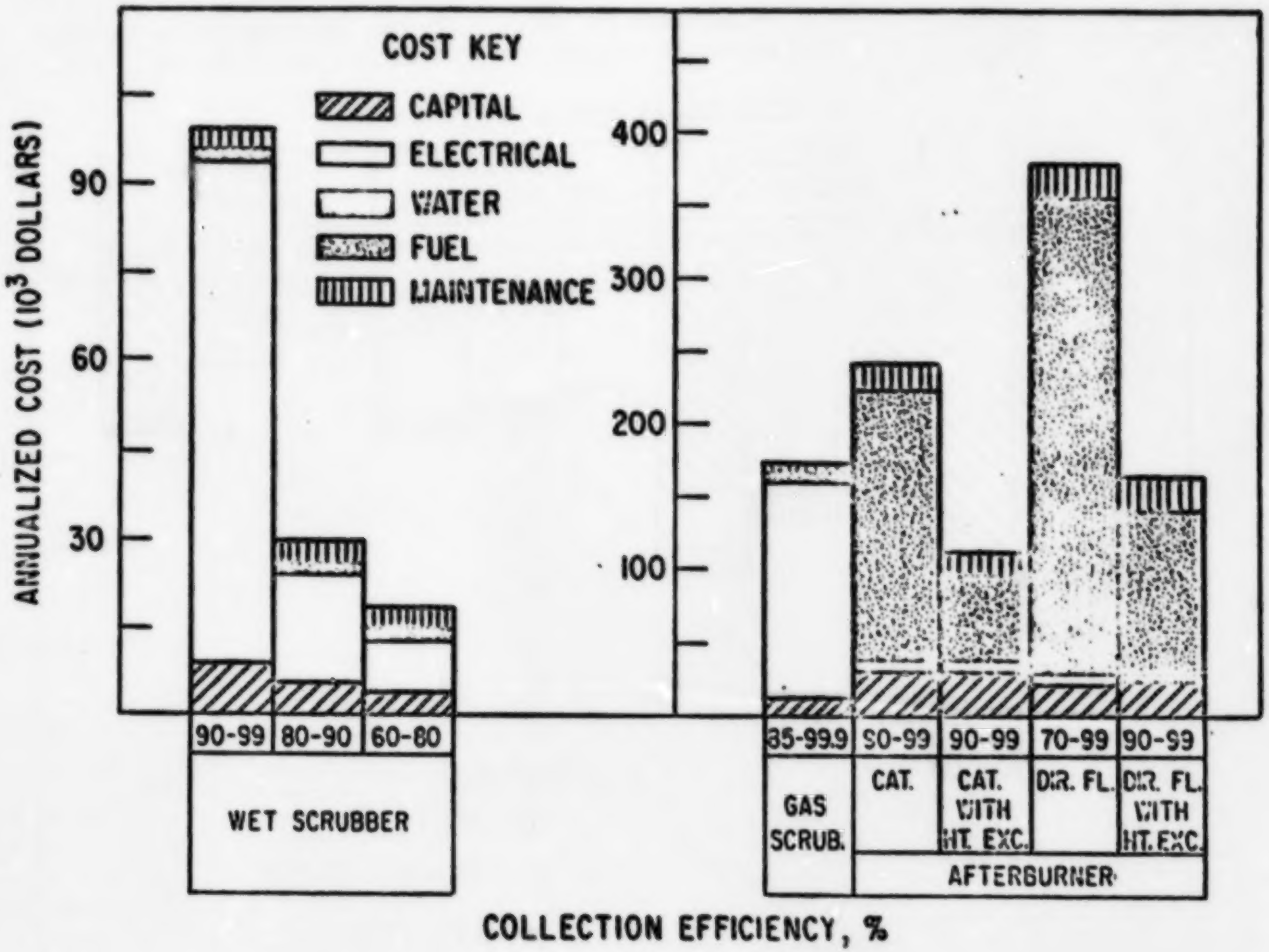

Figure B.4. Annualized costs for scrubbers and afterburners at 60,000/acfm and 8,760 hours of operation

Table B.9. CALCULATION OF INVESTMENT AND ANNUALIZED COSTS FOR SCRUBBERS AT 60,000/acfm AND 8,760 HOURS OF OPERATION

	WET SCRUBBER			GAS SCRUBBER
	HE	ME	LE	
Purchase Cost	13680	13680	8700	15060
Installation Cost	27360	13680	8700	30120
Total Installed Cost	41040	27360	17400	45180
Annual Capital Cost	8290	5532	3518	9135
Operation Costs	88380	20760	7830	164820
Electrical	88200	20580	7650	164640
Liquor Consumption	180	180	180	180
Fuel	---	---	---	----
Maintenance Costs	3300	3300	3300	4980
Operation and Maintenance Costs	91680	24060	11130	169800
TOTAL ANNUAL COST	99970	29592	14648	178835
Collection Efficiency	90-99	80-90	60-80	85-99.9

Table B.10. CALCULATION OF INVESTMENT AND ANNUALIZED COSTS FOR ELECTROSTATIC PRECIPITATORS AND FABRIC FILTERS AT 60,000/acfm AND 8,760 HOURS OF OPERATION

	Electrostatic Precipitator		
	HE	ME	LE
Purchase Cost	37380	26460	19080
Installation Cost	16170	18520	13360
Total Installed Cost	53550	44980	32440
Annual Capital Cost	10828	9095	6560
Operation Costs	3153	2050	1498
Electrical	3153	2050	1498
Liquor Consumption	---	---	---
Fuel	---	---	---
Maintenance Costs	1668	1668	1668
Operation and Maintenance Costs	4821	3718	3166
TOTAL ANNUAL COST	15649	12813	9726
Collection Efficiency	95-99.5	93-99	80-99

	Fabric Filter		
	H Temp.	M Temp.	L Temp.
Purchase Cost	50280	26880	19500
Installation Cost	37310	20160	14625
Total Installed Cost	87590	47040	34125
Annual Capital Cost	17700	9511	6900
Operation Costs	7706	7706	7706
Electrical	7706	7706	7706
Liquor Consumption	---	---	---
Fuel	---	---	---
Maintenance Costs	4164	4164	4164
Operation and Maintenance Costs	11870	11870	11870
TOTAL ANNUAL COST	29570	21381	18770
Collection Efficiency	95-99.9	95-99.9	95-99.9

Table B.11. CALCULATION OF INVESTMENT AND ANNUALIZED COSTS FOR MECHANICAL COLLECTORS AT 60,000/acfm AND 8,760 HOURS OF OPERATION

	Gravity Collector		
	HE	ME	LE
Purchase Cost	19560	9300	3360
Installation Cost	13040	6200	2240
Total Installed Cost	32600	15500	5600
Annual Capital Cost	6592	3134	1132
Operation Costs	780	780	780
Electrical	780	780	780
Liquor Consumption	---	---	---
Fuel	---	---	---
Maintenance Costs	1200	1200	1200
Operation and Maintenance Costs	1980	1980	1980
TOTAL ANNUAL COST	8572	5114	3112
Collection Efficiency	30-50	20-40	10-30

	Dry Centrifugal Collector		
	HE	ME	LE
Purchase Cost	11820	9420	5940
Installation Cost	5910	4710	2970
Total Installed Cost	17730	14130	8910
Annual Capital Cost	3585	1904	1802
Operation Costs	4680	4680	4680
Electrical	4680	4680	4680
Liquor Consumption	---	---	---
Fuel	---	---	---
Maintenance Costs	1200	1200	1200
Operation and Maintenance Costs	5880	5880	5880
TOTAL ANNUAL COST	9460	7884	7682
Collection Efficiency	80-98	50-80	30-80

Table B.12. CALCULATION OF INVESTMENT AND ANNUALIZED COSTS FOR AFTERBURNERS AT 60,000/acfm AND 8,760 HOURS OF OPERATION

	AFTERBURNER			
	Catalytic	Catalytic w/ Heat Exchanger	Direct Flame	Direct Flame w/ Heat Exchanger
Purchase Cost	90900	90900	68440	68440
Installation Cost	22725	22725	17110	17110
Total Installed Cost	113625	113625	85550	85550
Annual Capital Cost	22600	22600	17000	17000
Operation Costs	206541	86205	353541	134133
Electrical	1541	1541	1541	1541
Liquor Consumption	----	---	----	----
Fuel	205000	84664	352000	132592
Maintenance Costs	16000	16000	16000	16000
Operation and Maintenance Costs	222541	102205	369541	150133
TOTAL ANNUAL COST	245141	124805	386541	167133
Collection Efficiency	90-99	90-99	70-99	90-99

B.3 COMPARISON OF THE STRATEGIES WITH THE COST MODEL APPLIED

The cost model described in the previous section provided an example of the results obtained from the application of the cost model to a typical point source. This section compares the two strategies, emission-density-zoning and point-source control, on an area basis. To compare the two strategies on an area basis, consider as an example a one-square-mile area and the cost of control when industry is added to the area. For the same gray iron foundry as before, the least expensive applicable device is the electrostatic precipitator, at $9,726. When gray iron foundries are added to the area, each will be required to install an electrostatic precipitator for point-source control. As a result, the cost rises linearly. But when the EDLZ strategies are applied, the cost is a function of the amount of land. The gray iron foundry, which is classed as heavy industry, is allowed to emit 3.3 tons/day/mi^2 or 275 lbs/hr/mi^2. The reductions required to achieve the emission-density limits are formulated in Table B.13. They range exponentially from 21.4 percent for one foundry in the square mile area to 92.1 percent when ten foundries are located in the same area. The annualized costs associated with the reduction in particulate emissions also rises exponentially, for the foundry with a large amount of land can put on a less costly control device than a foundry with limited land resources. A comparison of the annualized cost of the two strategies is presented in Figure B.5. EDLZ is an effective control for particulate emissions, comparable in cost to PSC.

Table B.13. EMISSION REDUCTIONS REQUIRED AS INDUSTRY IS ADDED IN THE REGION

Plants (no/sq mi)	Allowable Emissions (lb/hr/acre)	Actual Emission (lb/hr/acre)	Reduction Required (percent)
1	275	350	21.4
2	275	700	60.2
3	275	1050	73.8
4	275	1400	80.3
5	275	1750	84.3
6	275	2100	86.9
7	275	2450	88.8
8	275	2800	90.1
9	275	3150	91.2
10	275	3500	92.1

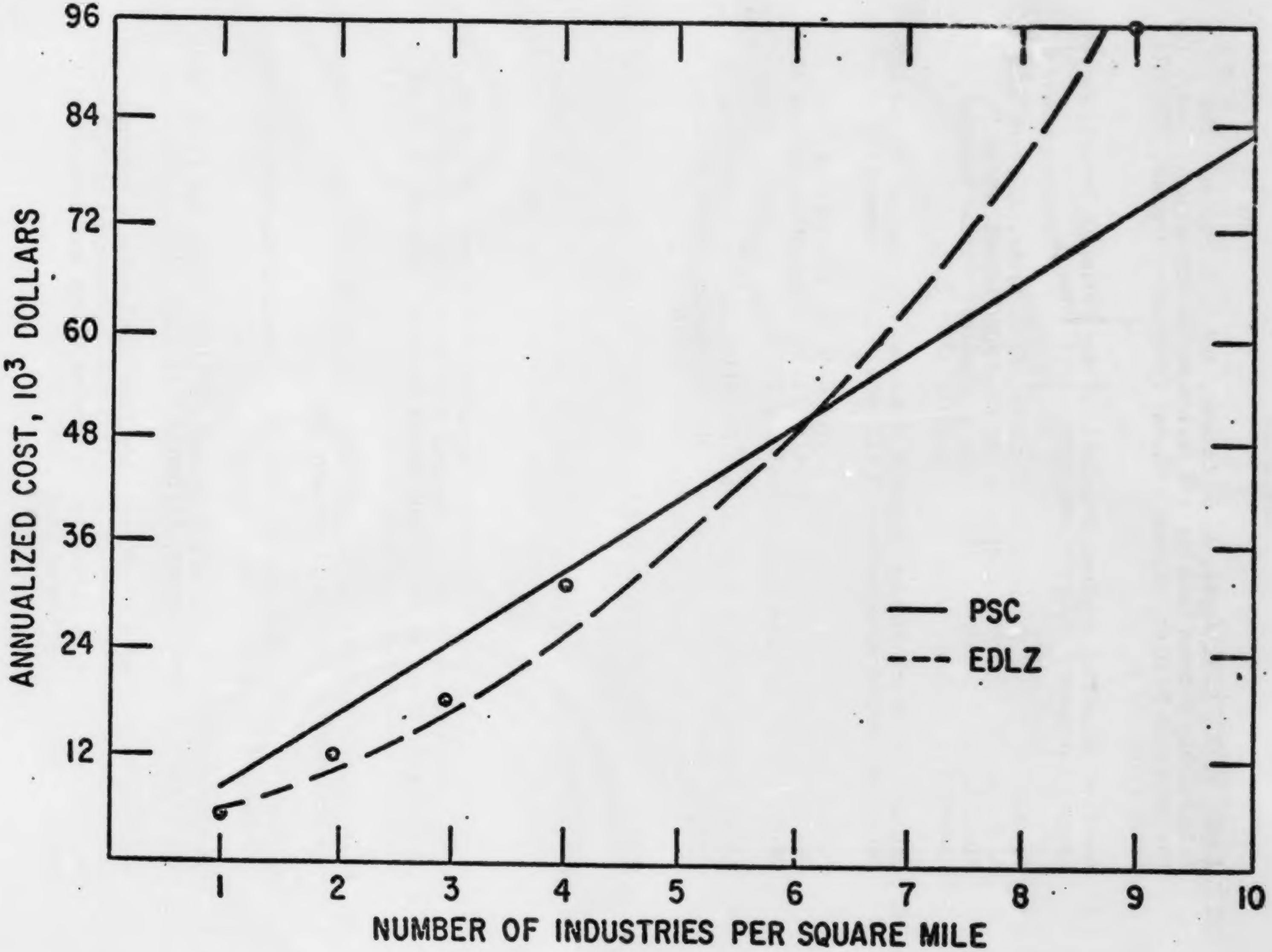

Figure B.5. Annualized costs comparison of the strategies by increasing industry

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